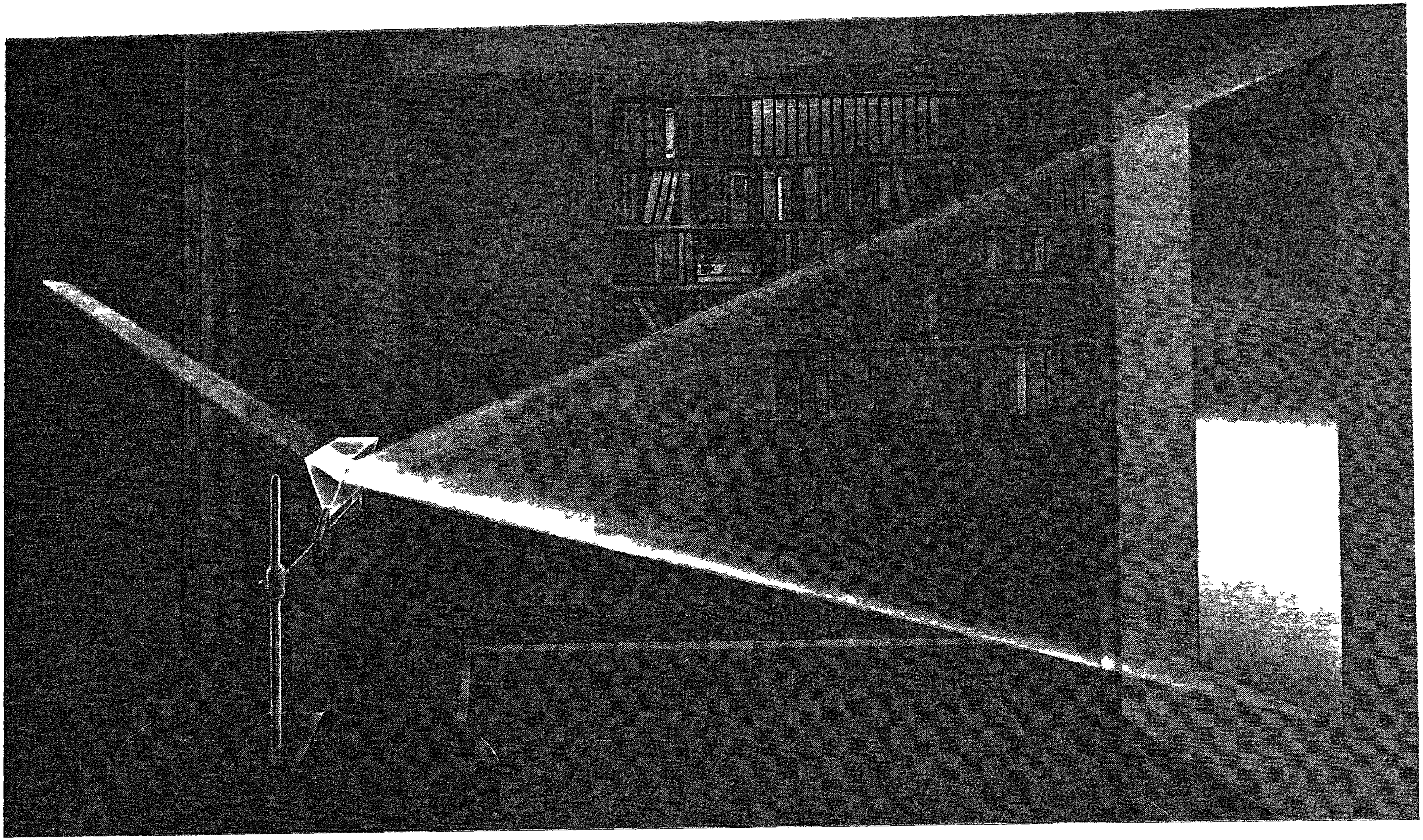
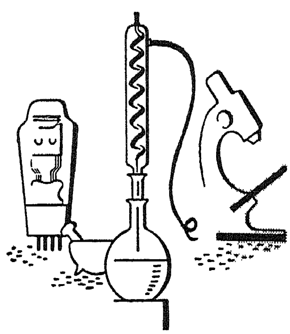


HOW A PRISM ENABLES MEN OF SCIENCE TO ANALYZE LIGHT

The sun's light, passing through a slit in the curtain, is broken up into the colors of the visible spectrum by a prism, like that used in a spectroscope

THE BOOK OF
POPULAR SCIENCE



volume 7

THE GROLIER SOCIETY INC.
Publishers of *THE BOOK OF KNOWLEDGE*
NEW YORK · TORONTO

PRINTED IN THE UNITED STATES OF AMERICA

3

CONTENTS OF VOLUME VII

HOW BUTTONS ARE MADE

The Mussel Fisheries and Pearl Button Industry of the Mississippi River

THE STORY OF VEGETABLE IVORY AND MUSSEL

TO the average person the button is a rather trivial object. Indeed the word has always been used in comparison as of something of little value. Yet buttons are among the most indispensable of small conveniences, and the use of them as such marks a high stage of civilization. The savage fastens his blanket or tunic, his leggings and moccasins, with strings. The flowing garments of the Greeks and Romans were also confined by strings and they wore an occasional gem to fasten the toga at the neck. Indeed, the button first appears not so much for use as for ornament.

A number of very ancient buttons were discovered by Professor Flinders Petrie in a tomb at Kopt, Upper Egypt, some years ago. The oldest of the lot, probably the oldest in the world, is of amethyst and about one inch in diameter. It is Egyptian in design, although clearly made by foreigners and represents a sacred hawk, which was the emblem of a royal soul, standing facing another hawk with the ankh, emblem of life, between them. A captive lies below the hawks. This button is credibly connected with a period 2500 B.C. Another interesting button found by the same explorer was taken from a tomb at Negadah, Egypt, with a quantity of beads of the Twelfth dynasty, which connects it with a period 2000 B.C. The button, in which there is no trace of Egyptian ideas, is of lapis lazuli; the design cut thereon appears to be an ape walking, with some inexplicable lines above the back of the ape. Below is the "thunderbolt", by far the earliest example of that famous sign known to history. Both of these buttons have piercings through the shank for the fastenings. Buttons sewed through small holes close to their edges are of a period somewhere about 2000 B.C., for in those known as Greek "island stones", made of blackened limestone, this very arrangement prevailed.

Buttons were first used in southern Europe about the thirteenth century, and were applied to dress for purposes of ornamentation only. In a manuscript poem written not later than 1300, we find the first mention of them where the hero is described as wearing buttons from his elbow to his hand. The employment of buttons increased to such an extent in the fourteenth century that their lavish use on fashionable attire was the occasion of unfavorable comment in the literature of that period. During the following century they were somewhat less in vogue. Lace and points appear to have superseded them, but they recovered their ascendency in the sixteenth century and were worn in great numbers on the dress of both sexes. They were of infinite variety as regards size, shape and material, which included gold, silver, brass and other metals, wood, horn, bone, glass, silk, cloth and velvet. In the time of Charles I, handkerchief buttons were much in style. Tastes were extravagant and we find frequent mention of buttons made of diamonds and other precious stones. Louis XIV is said to have had a positive mania for buttons, spending in a single year, that of 1685, over $600,000 for them. He bought two diamond buttons for $14,000, 75 for $120,000, and the set for a single vest cost over $100,000.

The kind of button, if consisting of a precious or semi-precious stone, a crystal or gold, worn on the hat in China, used to indicate to which of the social ranks one belonged. In contrast to the use of the button for purposes of adornment, we find eventually its development into the knob around which man fastened the cords or loops of strings attaching or attached to his garments. This marked an important step in button evolution, because from that time on it served a useful instead of only an ornamental purpose, and became an indispensable article of dress.

The history of button-making is in many ways a curious one. Dating no further back than the reign of Queen Elizabeth as a commercial industry of any considerable importance in England it has undergone extraordinary changes. Birmingham has always been the principal seat of manufacture there. The days of its greatest preëminence included the latter portion of the eighteenth and the early part of the nineteenth centuries, when it was the fashion to wear coats with innumerable gilt buttons. Early buttons were of cloth over a wooden disc; or of gold, steel or ivory, the last three the work of the goldsmiths who were very expert in the art of chasing and carving. Gilt buttons were first made in 1760. From that time to the present, the industry has grown rapidly, particularly in France, Germany, Great Britain, Switzerland and the United States. In the State Capitol at Hartford, Connecticut, there is a remarkable collection of buttons that gives some idea of the infinite variety that may be attained in manufacture. There we find a collection of thirty-four strings, each containing twenty-seven hundred different styles, and there are no duplicates in the entire collection.

The many varieties of buttons used on clothing may, in general, be divided into two main classes, according to the manner in which they are attached to the garment. In one class they are provided with a shank which may consist of a metal loop or of a tuft of cloth or similar material, while in the other they are pierced with holes through which the threads are passed.

The beginnings of the industry in the United States and its variety of product

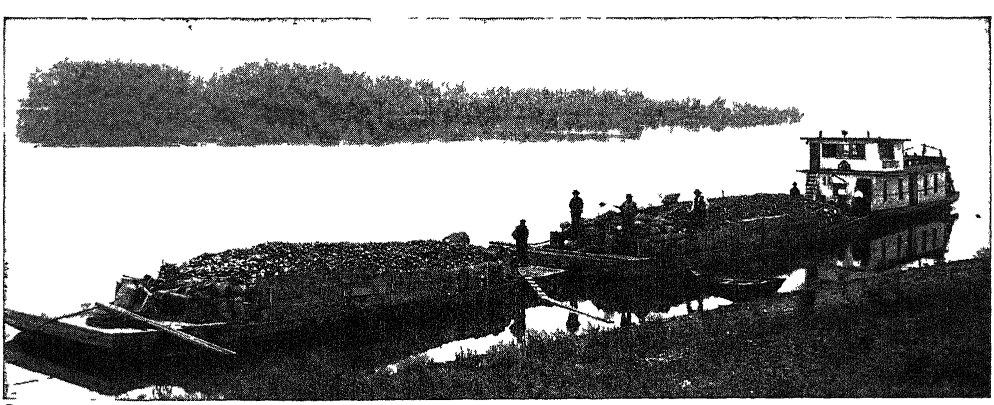
Each class is made in a great variety of material and an almost infinite diversity of form. The shank buttons are usually made on the shell plan, and consist of two plates of metal with a filling of pasteboard or cloth between them, each plate having the edges turned back, and the one securely pressed into the other by machinery. The face may be covered with cloth or may be of decorated metal. The back has a hole or collet in the center through which the metal shank or cloth tuft is introduced. The principle on which all such buttons are made is due to B. Sanders, a Dane, who in 1807 moved from Copenhagen to Birmingham, and there began their manufacture. He used a metal shank and his son introduced a cloth tuft in its place. Subsequent improvements were made by other inventors, reducing the cost and increasing the rapidity of production. On this account this kind of button has had an enormous sale. In spite of the innumerable modifications that have developed, shell buttons may be classed under two heads — the decorated metallic shell buttons, which were originally gilded or silvered by early processes, subsequently superseded by electroplating; and the cloth-covered buttons, made in satin, broadcloth, velvet, silk, mohair, linen, cotton and every other description of textile fabric. The manufacture of covered buttons was not attempted in the United States until about 1825 or 1826. At that time Samuel Williston, who was the founder of that branch of the industry in this country, began covering buttons by hand at Easthampton, Mass., and by the gradual introduction of machinery laid the foundations of an extensive business. At the present time the tendency of fashion is to abandon to a considerable degree the shell button and return to the older form with two, three or four holes.

Metal buttons form a numerous class by themselves, and include those for uniforms and trousers, fancy, gilt, stamped, chased or enameled buttons, and many cheaper varieties in iron and other metals.

They are largely produced from rolled sheet brass. Circular disks called "blanks" are first punched out of the brass, or other metal, by means of a fly press which consists of a vertical iron screw with triple thread, to which is attached a horizontal arm, bending downward at the end to form a handle. A punch attached to the press rises and falls with the motion of this handle and rapidly cuts out the blanks. When large quantities of one pattern are required, an automatic machine is used, which cuts out a number of blanks at one blow. The blanks, after being annealed, are afterwards stamped, which depresses the center and forms the edge. The holes are also punched by machinery. When shanks are used they are formed of wire by a separate machine which cuts off the pieces and bends them into loops of the required form. When these are soldered on, the buttons are dressed on a lathe. They are then finished by gilding, burnishing or lacquering. Gilded buttons are sometimes finished in a dead or frosted style. Livery and other kinds having a design in strong relief are stamped by a die in a stamping press. Most trouser buttons are made either from japanned iron stamped out by a heavy die or embossing swedge, or are made as shell buttons, with the back of paper or wood, and the whole thing turned out automatically by one machine. In the latter case the buttons are afterwards japanned. Numerous kinds of composite buttons are also part metal. Brass buttons were manufactured in Philadelphia as early as 1750. The first factory in Waterbury, Conn., which became a center of the American metal-button industry was established about 1800. Hardwood buttons were made there soon afterward.

In Bohemia and elsewhere pearl buttons are often manufactured by the poorer classes as a household industry in which all members of the family can engage, the smaller children sewing the finished product on cards. In Austria, France and Germany the work has been done largely by convicts. The shells are brought from the Red Sea and the Mediterranean, and it is said that there is danger that the beds will be exhausted. It takes a shell 20 years to mature. The manufacture of pearl buttons was introduced into the United States about 1855. The raw material first came from China and entered free of duty, but in 1891 the industry received a great impetus, owing to the discovery in the Mississippi of fresh-water mollusks admirably adapted to its use. Of the 400 species of mussels found in the river, several varieties are suitable for button manufacture, and if indiscriminate methods do not imperil the supply of material, this branch of the industry, which has attained large proportions, seems destined to still further growth.

The first person to engage in the manufacturing of buttons from the shells of our native fresh-water mussels was J. F. Boepple, who for many years had been similarly engaged in Germany. Due to



Courtesy Hawkeye Pearl Button Co.

TRANSPORTING SHELL TO SHIPPING POINTS OR DESTINATION ON NAVIGABLE RIVERS

The barges carry over 100 tons each.

the abundance of suitable shells in its vicinity, Muscatine, Iowa, was selected as the site of the first factory, and it became the center of this branch of the industry, which, as other river towns from time to time established factories, has become one of the principal businesses along that part of the Mississippi between Iowa and Illinois. The most remarkable development was witnessed in 1898, when no less than 36 factories were established during the first six months. The industry gives employment at good wages to large numbers of people, supports a very important fishery at which many hundreds of persons make a living, and, most important feature of all, transforms a hitherto useless product into a valuable commodity, placed on the market at a reasonable price.

Of the many mussel shells found in the Mississippi River and its tributaries, comparatively few are utilized in button-making. The requirements are sufficient thickness of shell, a uniform color of the surface and various strata, and a degree of toughness that will withstand factory treatment without cracking or splitting. Thin-shelled mussels are of no value. Even if originally thick enough, the necessary grinding and polishing reduce them to mere wafers. The preferred color is white, but cream-colored shells are also used.

Shells with pink, purple, yellow or salmon colored nacre are not suitable, as the color fades with age and is apt to lack uniformity. Some shells that satisfactorily combine thickness and color are nevertheless valueless, because they are soft and brittle and break easily during manufacture. Dead shells that have been exposed for a long time to the action of air or water also become useless.

The species of mussel found in the Mississippi River that is principally used in button-making is popularly known as the "niggerhead". It has the general shape of a common round clam, and is characterized by a very thick and heavy shell, with a black or dark-brown outside skin and a glistening white interior, the white being uniform throughout the thickness of the shell. It is of relatively small size, the largest being only 4½ or 5 inches in outside diameter and the average about 3 inches. It is found over immense areas, preferring muddy sand and muddy gravel bottom, but also frequently in sandy bottom. A number of abundant species, some of them resembling the niggerhead in shape, are available, but are sparingly used, on account of lack of thickness, undesirable color, and brittleness, which causes the shells to crack in cutting, and the buttons to split in facing and drilling Several other species known along the Mississippi as "sand shells" are highly valued, and a number of kinds of "pocket-book" clams are more or less abundant and yield a good button of medium thickness. Some of the best mussels for button-making are not abundant, and the supply is irregular and uncertain. One of the best known of these is the "deer horn" or "buckhorn". It attains a large size; samples over 9 inches long have been taken from the Iowa River, and in the Mississippi it reaches a length of 6 inches or more.

Aside from the depletion of the beds by fishermen, a number of animals prey on mussels, among them the muskrat, the mink and the raccoon, the first being especially destructive. Catfish are also said to eat mussels. Physical causes are further responsible for extensive destruction of the bivalves. During freshets mud and sand are deposited on the beds and bury them. Droughts are also liable to expose the beds and cause much damage. Next to the operations of the fishermen, perhaps the most serious menace to the beds is the pollution of the water by refuse from cities and manufactures. In the early days of the industry, fishing was carried on from about August to December, and more recently it has been conducted throughout the year, even after the river is frozen. The principal fishing, however, is still done in late summer and fall, when the river is lowest. Ice-fishing is of comparatively recent origin, having been carried on first during the winter of 1896–1897. The quality of the shells is better in cold weather, when they are less brittle than warm weather, with prolonged exposure in boats, makes them.

The beds are worked with comparative ease Little experience is required, and owing to the shoal water in which mussels are found, they may be gathered with less difficulty than is ordinarily encountered in taking shellfish.

Mussels are gathered with various kinds of apparatus, all of which are simple and inexpensive. The contrivances which have been in use are the hand rake, the tongs, the rake hauled by a windlass, the dredge operated by steam and the bar with hooks. Though essentially alike, the rakes are of several patterns. The commonest form, known as the "shoulder" rake, has a wooden handle from 14 to 20 feet long attached to one side of an elliptical metal frame; on the under side of the frame are 12 to 14 iron teeth 5 inches long; the head of the rake is converted into a kind of basket by a piece of coarse wire netting attached to a frame. The rake is used from an anchored boat, the handle being placed over the fisherman's shoulder, and the rake placed up stream to the full length of the pole. The fisherman then slowly works the rake toward his boat, lifts it perpendicularly from the water and empties the mussels into the boat. This rake is also used through the ice. The tongs, known also as "scissors" rakes, are similar to the ordinary oyster and clam tongs. The dredge or rake used with a windlass is larger and heavier than the shoulder rake and of different shape. The bar with hooks, locally known as the "crowfoot" rake, is an ingenious contrivance depending for its action on the habits of the mussels themselves, and is now the leading means for taking them. It consists essentially of an iron rod 6 feet long to which are attached at intervals of about 6 inches a series of chains, each carrying a number of four-pronged wire hooks. The mussels rest on the bottom, or partly buried in the mud or sand, with their shells turned up stream and separated to admit the water, laden with oxygen and food. When touched they quickly close them, and if a foreign body is interposed between them it is tightly held. The fisherman throws the crowfoot rake overboard and allows his boat to drift downstream. As the prongs come in contact with the shells they close on them with so firm a hold that, when the dredge is drawn in, considerable force is required to detach the mussels. For anyone who has not seen the apparatus in use it is difficult to realize how effective it is. Often where mussels are abundant almost every prong will have one and sometimes two or three on it.


McKee Button Co.

It takes skill and experience to sort the shells that are used in the manufacture of pearl buttons.

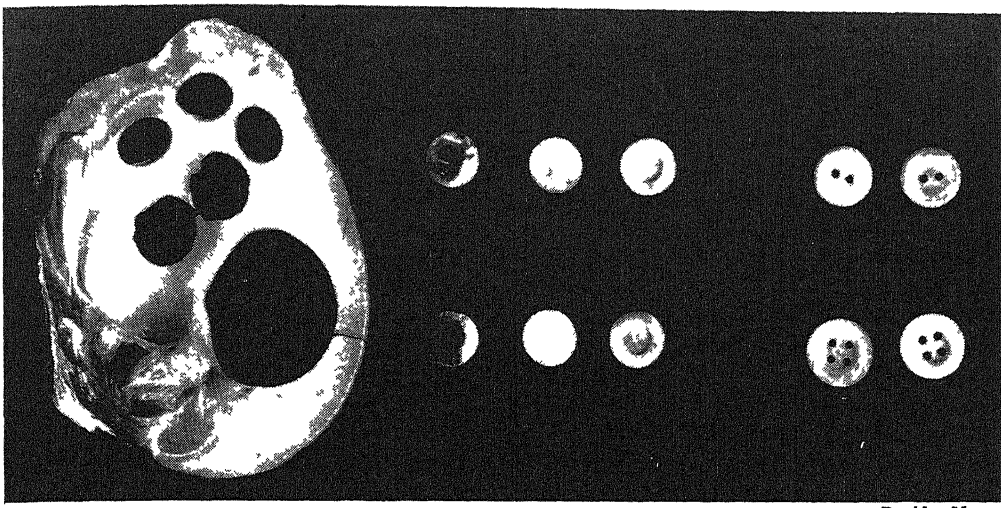
The fishermen have tanks, made of sheet iron, located at some convenient place on shore in which the catch is boiled 10 to 15 minutes, when the mussel falls or is readily picked out by hand. The shells are loaded in sacks and sent by steamer or taken to market in the fisherman's boat or heaped on scows and towed to the factory, or sold on the shore to buyers.

The Iowa and Illinois button factories located on the Mississippi obtain their supply of shells from grounds which extend a distance of some 200 miles, from Fort Madison to Sabula, Iowa. This part of the river is quite shallow, a necessary requirement for mussel growth and fishing. The natural tendency of some of the species is to form in more or less dense beds, while others are uniformly distributed. On some grounds practically all of the mussels are of one species, while on others several species may be mixed in varying proportions. The largest and most compact beds are formed of the niggerheads and muckets. On new grounds the niggerheads are sometimes so thickly disposed that practically the entire bottom over a large area is covered and the shells are often found several layers deep. In holes or depressions in the sandy or muddy bottom they are often discovered in thick piles, and many bushels may be taken from one of these holes.

The mussel shells as purchased from the fishermen are hauled in drays or wagons from the boats to the factories, where they are stored in covered sheds, the different kinds usually being kept in separate bins. Preparatory to being used, the shells are sorted into sizes by boys. Usually three sizes of niggerheads are recognized. Another preliminary step is the soaking of the sorted shells in barrels of fresh water for three to six days to render them easy to work. Even when only a few hours out of the river the shells become dry and brittle. It is necessary that they be used while wet, otherwise they crumble and split in manufacture. The next step is the cutting or sawing of the rough blanks. Each cutter has a pile of selected shells at hand, and, in the large factories, he is kept supplied by boys. Niggerhead shells are usually held with special pliers while being cut; these grasp the circumference of the shell and retain it fast while holding the shell at right angles to the saw. Some operators have the hand gloved or mittened, and use no pliers or pincers. At the larger plants a fine jet of water plays on the shell, as the saw revolves, in order to prevent the formation of dust and to keep it cool.

The fine dust is very irritating to the respiratory passages and eyes of the cutters, and at some of the factories is drawn into a tube by a current of air. The cutters in the smaller works often cover the mouth and nose with a cloth or sponge. The saws are made of flat steel strips, provided with fine teeth on one of the edges. These are accurately bent into cylindrical form and fitted into heavy iron holders; the latter are adjusted to a lathe in which they revolve on a horizontal axis. As the blanks are cut they pass back into the saw and holder and drop into a box provided for the purpose. From the cutting machine the blanks are taken to a weigher and recorder. By far the largest number of factories produce only rough blanks, which are sold to a local finishing plant or sent to large concerns in the east, some of which have established their own saw works on the Mississippi. The next step in the making of a complete button is the dressing or grinding of the back of the blank, to remove the skin and make an even surface. To accomplish this each blank has to be held with the finger against a revolving emery wheel. This is followed by turning or facing, which gives the front of the button its form, including the central depression. The next step is the drilling of 2 or 4 holes for the thread. The button is now complete, with the exception of the polishing process, this brings out the natural luster which has been lost in grinding, and which gives to these buttons their chief value. They are placed in mass in large wooden kegs, known as tumblers, in which they are subjected to the action of a chemical fluid at the same time that the tumblers are revolving on a horizontal shaft. By mutual contact combined with the effect of the fluid, the buttons become highly polished while the fluid is churned into a milky froth. After being washed and dried the buttons go to rooms where they are sorted into sizes and grades of quality, and then sewed on cards and packed in pasteboard boxes.

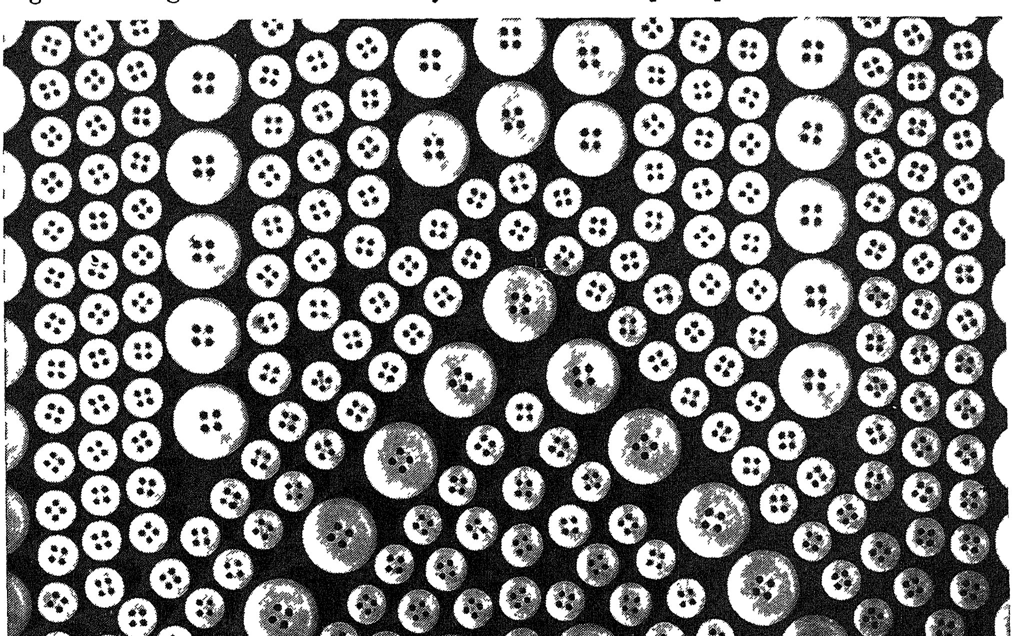
At Muscatine there is a small business done in treating buttons chemically to make them resemble "smoked pearl".



Brooklyn Museum

The evolution of pearl buttons from fresh-water mussel shells to the exquisite finished product.

The unit of measure of size of the buttons is the line, which is one-fortieth of an inch. The buttons manufactured on the Mississippi are from 12 to 45 lines in diameter. The largest, 40 to 45 lines in diameter, are made from niggerheads. A medium-sized niggerhead produces four or five 18 or 20-line blanks, while from the large shells eight or ten blanks may be cut. Sand shells average twelve 20-line buttons. The largest deerhorns produce as high as twenty-five or thirty 20-line blanks. In sawing the blanks a large part of the shell cannot be used, as it is incapable of being made into merchantable buttons. The relatively thin margin of the valves and the thick beak or umbo furnish the principal waste.



American Cyanamid Co.

The buttons shown above are made of melamine urea plastics. Plastics lend themselves excellently to mass production, nowadays most of our buttons are manufactured from these versatile materials.

The amount of the unserviceable raw material is extraordinarily large, though it varies with the different species and factories. It is estimated that in the aggregate it probably represents over 75 per cent of the weight of shells handled. In facing, grinding, drilling, and polishing the blanks, and in defective blanks, there is a further waste. With the principal mussel employed, the niggerhead, more than 90 per cent of the material, by weight, is finally discarded. If a market could be found for this enormous waste it would prove a boon to the industry. Though it is felt that it undoubtedly has a value, it has not yet been much used except to a very limited extent in road making. It is said to make a valuable fertilizer, but so far no great demand has been created.

The danger of exhausting the mussel supply

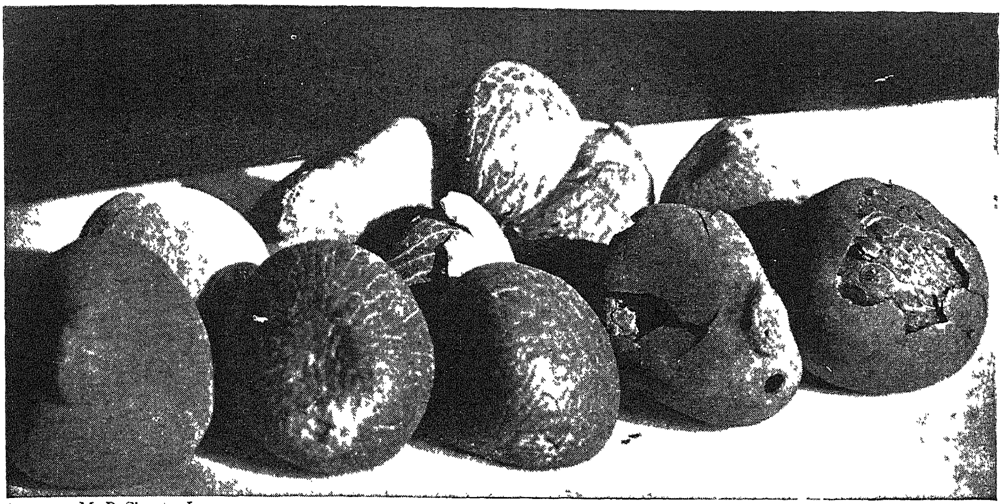
Although mussel fishing along the Mississippi River is comparatively new, there has been a more or less marked reduction in the abundance of mussels of all kinds utilized in making buttons, and in some localities the depletion of the beds has been almost complete. As the time required for a niggerhead mussel under normal conditions to reach a marketable size is 10 to 20 years, the serious effects of indiscriminate fishing are evident, and great solicitude has been felt by the button-makers and others lest their raw material should be exhausted. This has been the subject of recent investigation by the United States Fish Commission, and measures have been advocated through which it is thought the supply will be indefinitely maintained.

Some difficulty was at first experienced in putting on the market buttons made from our native fresh-water shells, but the demand rapidly developed, as their quality and price became known, and at present Mississippi River buttons are sold in every state in the Union and even in foreign countries. Button exports from the United States amount to some 900,000 gross, and are valued at more than $250,000. The imports of buttons, however, often exceed the exports.

How the nut of a palm tree is utilized in button making

Vegetable ivory has long been a favorite material for the manufacture of buttons because it can be readily sawed, carved and turned in lathes into all sizes and shapes, while the texture of the material is such that it readily absorbs dyes and also takes on a high and permanent polish. To look at a nicely made button that so artistically harmonizes with the fancy grays, browns or blues of men's attire, the casual observer would hardly imagine that it is a purely vegetable product, in fact, the seed of a tree. It has been little more than fifty years since some rubber gatherers in the forests of northern Ecuador first told of a peculiar species of palm which they found in great numbers, whose fruit resembled in form and color the miniature head of a negro. These nuts they therefore called "negritos", and it was found that the kernels, when thoroughly dried, had the appearance and texture of dentine ivory. Sample lots were sent to Europe for experimental purposes, and although they were at first thought to be useless, it was found upon further investigation that they furnished an ideal material from which to manufacture buttons and other small ornamental objects, for which the more expensive ivory had hitherto been used. This seed or nut is now known almost everywhere as the vegetable ivory nut. In its native land it is called the Tagua, or Coroza nut. The photograph shows the fruit of one of these, *Phytelephas macrocarpa, Palmæ.*

The tagua palm is found near the west coast of South America, from southern Panama, through Colombia, Ecuador and northern Peru. It is most plentiful along the eastern slopes of the Andes and flourishes in groves along the river valleys at varying elevations above sea level. The tree is, in reality, a stunted palm fern and grows very slowly to a height of 10 to 20 feet. On the whole it presents a fine appearance. The leaves, bearing a very close resemblance to those of the cocoanut palm, are thrown out around the central stem, which after growing and shedding the

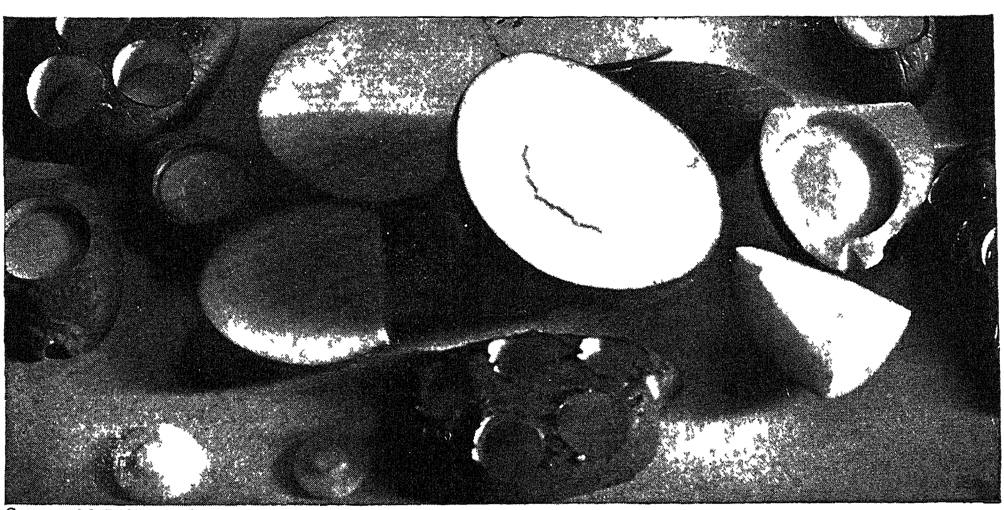


Courtesy M B Shantz, Inc

IVORY NUTS FROM WHICH THE OUTER HUSK HAS BEEN REMOVED

leaves for 5 or 6 years, forms the trunk, at that age not over 3 or 4 feet high, crowned by a canopy of leaves resembling large green feathers. At this time fragrant blossoms appear at the bases of the lowest leaves to be fructified by the pollen borne to them by the winds or carried by the myriad insects from the nearby male tree. Each fruit is composed of a dozen or more separable fruits, one of which, broken open, is shown at the right side of the picture. In each section of the large fruit, there are four to six seeds the size of an egg. These are embedded in pulp and many coverings and are first in the form of sacks of sweet, refreshing liquid that changes into a soft, delicious pulp, and finally becomes the hard nut of commerce.

The nuts mature very slowly, requiring fully a year from blossom to full ripeness. A collection of 60 to 90 nuts in groups of 5 or 6 are incased in one huge, knobby husk resembling a chestnut burr but much larger. (See frontispiece of this chapter.) This head opens at the bottom when the nuts are ripe and lets them fall to the ground. They are covered with a thin, oily substance which attracts the wild hog, guanta, guatusa, squirrel and other rodents that leave the nuts clean for the gatherer.



Courtesy M B Shantz, Inc

SECTIONS OF IVORY NUTS

Care in sawing must be taken to avoid the cracks that occur in drying.

There still remains a creamy white dry substance which rubs off in handling and leaves the hard black shell resembling the skin of the negro in color and texture. The nuts are about the size of small potatoes, of very hard, white composition; fine-grained, and closely resembling dentine ivory. The finest nuts come from Ecuador and Colombia. Here, in or near the fertile river valleys the tagua palm flourishes in groves, scarcely any other vegetation being mingled with it. As the tree grows wild and uncultivated, the time of bearing and the length of life of the tagua palm has not been definitely ascertained, but it is claimed that they begin bearing in their sixth year and that they live from fifty to one hundred years.

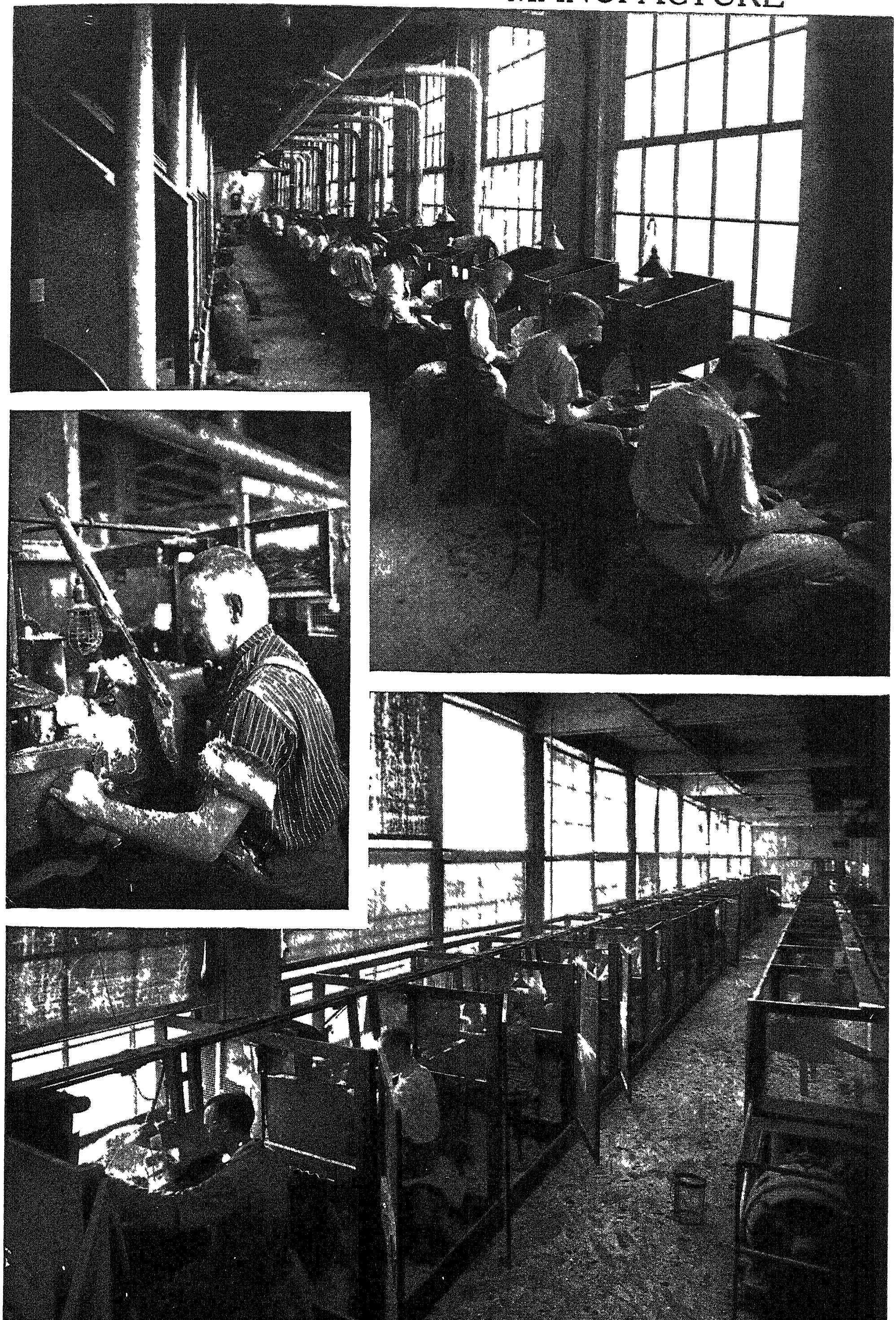
The largest tagua forests are from three to six days canoe journey from Esmeraldas and Guayaquil, the chief ports of Ecuador. The native gatherers, known as *taguaros*, work in pairs or small parties, and subsist largely on wild game. Having established camp, as near as possible to the forests, baskets are woven which will hold about 200 pounds of nuts and rafts built on which to transport them down stream to the markets. If the trees are distant from camp mules are used, but usually the natives carry the baskets on their backs, a very exhausting task attended with danger from snake bites and disease brought on by constant exposure. When ten or fifteen tons of nuts have been secured, the filled baskets are placed in rows around the outer sides of the deck of the raft or boat, leaving an open space in the center for loose nuts, and the craft is headed down the river to one of the trading stations, where they are sacked and shipped to the button factories of the world.

The ivory nuts as they are received at the factory look very much like small potatoes. They are still incased in exceedingly hard flint-like shells which are capable of resisting the hardest steel, yet can be cracked open with a sharp blow. To remove the kernel they are spread out and dried in a temperature of about 100° F. until the shells become loose and easily separable.

They are then placed in tumbling barrels or drums, and are thus mechanically separated from the shells. After several hours of tumbling the nuts are individually inspected and the minutest particles of shell which may still adhere are removed Next they are taken in an automatic carrier to the sizing drums where they are automatically sized and bagged. Thence they go immediately to the saw room where the pieces of button slabs are cut from around the core of the nut by high-speed circular saws. The core is usually more or less hollow and pithy and has to be discarded. The pieces, or green slabs, are now subjected to a high temperature in dry kilns where they undergo a period of curing for about six days to remove every bit of moisture. Each piece is now as hard and dry as a bone, and, regardless of how it may be swollen or soaked in subsequent process of manufacture, it always returns to its present state of hardness. After the pieces are sorted by revolving drums they are ready for the turning room. But before being put on the lathes, the slabs are immersed in a steaming hot bath to moisten the outer surface and prevent cracking. In the turning room the ivory is rapidly cut into the required size and shape of the "blanks".

The most accurate and complicated machines in the factory are those which drill the holes. It is also their function to ream the edges of the holes, so they will not cut the thread, and if it is a niched button, to cut the little grooves on the faces between the holes. This is all done in one operation; the blanks from the turning room being poured in at the top, the machine automatically faces each button in the proper direction, and holds it in place while the holes are drilled and reamed. As soon as the button blanks have been drilled they are taken to the drum room and rolled in large tumbling barrels with polishing material which gives them an extremely smooth surface. The next process to which the white ivory is subjected is that of coloring, giving it the shade and design to match or harmonize with the woolen for which it is intended, perhaps not yet on the market.

INITIAL STAGES OF MANUFACTURE



Courtesy M. B. Shantz Inc. and Art in Buttons Co.

SAWING IVORY BUTTONS (*above*) AND TURNING THEM INTO CIRCULAR FORM

Buttons may be either in solid or mottled colors. The dyeing of the first class is a fairly simple process, that of the latter is more complicated. First they are soaked in water to open the pores and further prepare the surface for the reception of the coloring matter. Then they are placed face up on a pin board containing a gross of buttons, which, in turn, is passed to a dyer, who places a chart or stencil over the pin board, and with the aid of an air brush sprays the buttons with a "resist" dye. The chart is then removed and the board passed to a second dyer who, with the aid of a similar chart, sprays the buttons with the "color" dye, and sets it out to dry. When the buttons are thoroughly dry they are taken from the pin board and placed in a vat of color bath or developer, which brings out the spray color and renders it fast, and also gives a medium shade to that part of the button which has not been sprayed at all. The color being firmly fixed, the "resist" is removed and there is left a finished button, though rather dull in luster. To bring out the color and finish, they are again drummed for several hours until they acquire a high polish. There is no limit to the variety and beauty of coloring which can be produced in this way. Great variety may also be obtained by the kind of finish, and the button may be either polished, dulled or pressed, or a combination of any of these. Finally the buttons are taken to the carding room, where they are individually inspected, sorted, shaded and sewed on cards. Before being placed in boxes they are again inspected on the cards to see that all those on one card are exactly the same, and then packed ready for shipment.

Probably few people realize the importance of this branch of the button business and the extent to which the industry has grown in the last few years. The United States buys annually thousands of tons of tagua nuts for which is paid more than a million dollars The vegetable ivory factories in this country represent an investment of several million dollars and give employment, directly and indirectly, to thousands of workers.

This constitutes fully one-third of the button business of the entire country The leading center of manufacture is Rochester, New York, which has the three largest plants, and makes, it is said, the highest grade of goods in the world. In following the process of manufacturing buttons from ivory nuts the tremendous waste involved is again to be noted. Through shrinkage, sawing and defects, more than half of the original shipment is lost and the manufacturer pays for the handling and transportation of an enormous amount of unused material. In the reduction of the product from nut to slabs the element of skill is almost negligible, and this, it is thought, could be easily accomplished in the country where the tagua palm grows. Steps have already been taken in this direction.

It has been said by a leading manufacturer in the Birmingham district that it is easier to write out a long list of material from which buttons have been made than to name one from which they have *not* been made. Among the animal substances used are ivory, bone, horn and hoof. Buttons made of hoof under the name of "horn buttons" were introduced about the middle of the nineteenth century by E. Bosset of Paris. These had a great success in their day and were made in enormous numbers by pressing them in heated dies in which the design was cut They were manufactured extensively for a good many years at Birmingham, and sent to all parts of the world. Horn buttons were made in the United States as early as 1812. They were very popular for years, but have given way to ivory, bone and vegetable ivory, mother-of-pearl and celluloid. Mother-of-pearl buttons are formed of the beautiful substance of which the large flat shell of the pearl oyster consists. Small cylinders are cut out of the shells with a tubular saw, split into disks, drilled with holes, and polished with rotten stone and soft soap, or with ground charcoal and turpentine. Shirt studs as well as flat and globular buttons with metal shanks are also made of mother-of-pearl, which may be either of the ordinary color or smoked. Pearl shirt

buttons are made in great quantities both in the United States and in Europe, and often of a cheap substitute. Porcelain buttons were a few years ago nearly all of French manufacture, but they are now made principally in Prague. The plastic clay is pressed into molds of plaster of Paris in the same way that small objects are usually produced in earthenware. Celluloid buttons are made in mold like the vulcanite and horn.

More or less expensive buttons are made of ornamental stone, such as agate, jasper and marble. Occasionally, they are formed of amber, jade, or of still more costly materials, as pearls and gems. Glass buttons are made in great variety. For "punched" buttons small rods of colored glass are heated at the ends, and pressed into shape by means of a pair of rather long hand pliers, on the ends of which are a die and its counterpart, likewise kept hot. Other kinds are cut out of colored sheet-glass, which is coated on the back with tin amalgam like a mirror. Along with these varieties some beautiful glass buttons are made in Bohemia, either partly or wholly of aventurine glass; and of this gold-spangled material, artistically inwrought with other colors, studs and solitaires still more remarkable for their beauty and minute patterns are made in Venice.

Fancy or ornamental buttons for women's dresses are sometimes made of combinations of cloth and glass or papier-mâché pearl, metal or choice woods, sometimes of vulcanite or glass, but oftener at the present time of silk, velvet, silk cords and figures, or what is known as passementerie, or of brocade and embroidered silk. These are usually made upon a wood foundation, especially if they are oval or fanciful in shape. Their manufacture is often carried on in connection with other dress trimmings. Different kinds of wood, such as beech, boxwood, rosewood, lignum-vitæ, zebra-wood and walnut are manufactured into buttons. Wood molds or cores for women's buttons, which are covered with cloth of the same pattern as a dress, are made in enormous numbers in the south of France.

Various kinds of composition buttons have been made since the industry was started in this country some fifty years ago. The first of these, a button resembling vegetable ivory, was produced from certain fossil and vegetable gums combined with finely comminuted carbonate of lime, feldspar or mica. Composition buttons are now made of many materials, among them the Irish potato, which, when combined with certain acids, becomes as hard as stone. Other materials are the casein from skim milk, blood and brown seaweed. A unique branch of the industry is the manufacture of campaign and society buttons, and of buttons on which photographs are reproduced or ornamental designs for purposes of advertising or ornament. These are usually made from celluloid.

In recent years the old hand methods of making buttons have been superseded by machinery. Numerous ingenious devices have been invented whereby many kinds of buttons are made wholly or in part by automatic devices and turned out with marvelous rapidity In the United States there are some 200 button factories with the value of their products placed at more than $20,000,000. The factory payroll is more than $8,000,000

In England the city of Birmingham is still the seat and center of the button trade, which, however, is much more largely developed in France and Germany. Machinery has recently been introduced into the button-making factories of Japan, and with the abundant supply of shells found on the neighboring islands and imported from India and the Dutch East Indies the industry has grown enormously. Great quantities of pearl buttons are yearly exported to Great Britain, France and Germany, and the trade is rapidly increasing. Notwithstanding this newly developed branch of the industry and the growth in other countries, notably Germany, census reports show that our exports of buttons are steadily increasing, while our imports, formerly great, have decreased to an extent that reveals what an important place among our leading in dustries the button business has assumed.

ONE HUNDRED CALORIE PORTIONS OF THE MOST COMMON FOODS

(*Note:* Unless otherwise stated, the foods are uncooked)

Foods	*Approximate Measure of 100 Calorie Portions*
ANIMAL FOODS (*Except Fats*)	
Buttermilk	1 ⅓ cup
Cheese (American)	1 inch cube
Cheese (Cottage)	⅓ cup
Cheese (Neufchatel)	2 ½ tablespoons
Cream, thin (18%)	3 tablespoons
Cream, thick (40%)	1 ¾ tablespoons
Eggs (whole in shell)	1 ⅓ egg
Eggs (white)	6 whites
Eggs (yolk)	1 ⅔ yolks
Gelatin	2 ¼ tablespoons
Milk (whole)	⅝ cup
Milk (skim)	1 ⅙ cups
Milk (condensed—unsweetened)	4 tablespoons
Milk (condensed—sweetened)	2 tablespoons
Milk (dried—whole)	
Milk (dried—skim)	
Oysters	About ⅞ cup or 15 to 20 oysters
Canned Salmon	⅓ cup
Meat (lean)	1 small serving
Fish	1 medium serving
FRUITS	
Apple (fresh)	1 very large
Apricots (fresh)	2 to 3
Bananas	1 large
Blackberries (fresh)	1 cup
Cranberries (fresh)	2 cups
Currants (dried)	¼ cup
Dates (dried)	4
Figs (dried)	2 to 3
Grapefruit	½ large
Grapes	40 to 50
Huckleberries (fresh)	1 cup
Lemons	3
Muskmelons	1 very large
Oranges	1 large
Peaches (canned)	2 halves
Peaches (fresh)	2 medium
Pears (fresh)	1 large
Pears (canned)	2 halves
Pineapple (fresh)	1 cup
Pineapple (canned)	1 slice
Plums (fresh)	4 large
Prunes (dried)	4 to 6
Raisins (dried)	¼ cup
Raspberries (fresh)	1 cup
Rhubarb (uncooked)	7 cups
Strawberries (fresh)	1 ½ cups
NUTS	
Almonds (in shell)	15
Peanuts (in shell)	15
Peanut butter	1 tablespoon
Pecans	12 halves
Walnuts	7 halves
SUGARS AND SYRUPS	
Chocolate	½ square
Cocoa	3 tablespoons
Honey	1 ½ tablespoons
Maple sugar	2 tablespoons
Maple syrup	2 tablespoons

Foods	*Approximate Measure of 100 Calorie Portions*
Molasses	2 tablespoons
Sugar	2 tablespoons
Sugar (brown)	2 ½ tablespoons
VEGETABLES	
Asparagus (fresh)	About 50 stalks
Beans (string) as purchased	2 cups or 3 to 4 servings
Beans (Lima) as purchased	1/6 cup
Beans (dried) as purchased	2 tablespoons
Beans (dried) cooked	½ cup
Beets (as purchased)	1 medium
Cabbage (as purchased)	⅓ head or 3 to 4 servings
Carrots (as purchased)	2 medium or 2 to 3 servings
Cauliflower (as purchased)	½ head or 3 to 4 servings
Celery (as purchased)	2 heads
Chard (cooked)	2 cups or 3 servings
Corn (canned)	6 tablespoons
Corn (green)	2 small ears
Cucumbers (as purchased)	1 large
Lettuce (as purchased)	1 ½ solid
Olives (as purchased)	6 to 7
Onions (as purchased)	4 medium
Parsnips (as purchased)	1 large
Peas (canned)	1 cup
Peas (dried) as purchased	2 tablespoons
Peas (dried) cooked	½ cup
Peas (green) as purchased	
Potato (white) as purchased	1 medium
Potato (sweet) as purchased	1 medium
Spinach (as purchased)	3 ½ quarts
Spinach (cooked)	2 cups or 3 or 4 servings
Squash (cooked)	1 cup
Tomatoes (fresh)	4
Tomatoes (canned)	1 ¾ cups
Turnips	4 small
CEREALS	
Cornmeal	3 tablespoons
Cornflakes	1 cup
Cornstarch	¼ cup
Graham crackers	3 to 4 crackers
Soda crackers	5 crackers
Graham flour	¼ cup
Hominy	¼ cup
Macaroni	¼ cup
Oatmeal	3 tablespoons
Oats (rolled)	¼ cup
Rice	2 tablespoons
Shredded wheat	1 biscuit
Tapioca	2 ½ tablespoons
Whole wheat flour	¼ cup
White flour	¼ cup
FATS	
Bacon	1 full slice
Butter	1 tablespoon
Cod Liver oil	1 tablespoon
Cottonseed oil	1 tablespoon
Lard	1 tablespoon
Olive oil	1 tablespoon

From *Your Weight and How to Control It*, edited by Morris Fishbein, M.D. (Doubleday, Doran & Co.)

WHAT IS A CALORIE?

How We Measure the Heat-Producing Value of Foods

A CALORIE is a unit of measure for heat, just as an inch and a foot are measures of distance, an ounce and a pound are measures of weight and a kilowatt-hour is a measure of electricity. We must distinguish between small and large (or great) calories. A small calorie represents the amount of heat required at a pressure of one atmosphere (approximately 14.7 pounds per square inch) to raise the temperature of one gram of water one degree centigrade. A large calorie is 1,000 times greater. It represents the amount of heat required, also at a pressure of one atmosphere, to raise the temperature of 1,000 grams—a kilogram—one degree centigrade.

How small and large calories serve as measures

Heat has long been measured in physical laboratories in terms of small calories. The large calorie measure is particularly useful in calculating the energy or heat value of our foods. After all, all the energy that is released in the body comes from food and, whether it is used for our activities or to keep the body warm, it is eventually almost entirely transformed in the body into heat. That is why it is satisfactory to speak of the energy-producing value of food in terms of large calories. Large calories in this case are referred to only as calories, "large" being understood.

Proteins, fats and carbohydrates (starch and sugar) are the main food elements that give energy. Foods are high or low in calorie value, therefore, according to the quantities of proteins, fats or carbohydrates they contain. The energy or caloric value of each of these food elements is determined by burning carefully weighed amounts of each in a heat- or energy-measuring machine called a calorimeter. A delicate thermometer is attached to this device, and it registers the heat that is produced when a given foodstuff is burned.

In one type of calorimeter, a man is enclosed in a chamber, the walls of which are effectively insulated so that no heat can escape. In the chamber there is a bicycle upon which the subject can do a carefully measured quantity of work; measured quantities of food and oxygen are made available to him. A stream of water is circulated through pipes within the chamber and is then led out from it. The heat generated by the subject within the chamber is carried off in the water and is measured.

The body is a sort of human machine where proteins, fats and carbohydrates are burned in order to produce energy. In the body the combustion of proteins is not so complete as it is outside of the body. The reason is that when proteins break down in the body, one of the products, urea, retains considerable energy as it passes from the body in the urine. (Urine is made up chiefly of urea.) In the case of carbohydrates and fats, combustion is about as complete within the body as it is outside of it. In the course of combustion the carbohydrate and fat molecules undergo various changes; in the end, however, they both yield carbon dioxide and water.

Determining the fuel value of foods

It is possible to determine the fuel or caloric value of proteins, or carbohydrates or fats; it is also possible to determine the fuel value of natural foods, such as eggs, milk, meat, potatoes and so on, which are made up of varying proportions of different food elements. Tables showing the fuel value of given weights of foods are useful in helping us to determine the calories that are provided by the diet. We give two such tables on the preceding and following pages.

ONE HUNDRED CALORIE PORTIONS OF SOME OF THE MOST COMMON RECIPES

Recipe	*Approximate Measure of 100 Calorie Portions*
BEVERAGES	
Chocolate	¾ cup
Cocoa	½ cup
Grape juice	½ cup
Orange juice	1 cup
BREADS	
Baking powder biscuits	2 small or 1 large
Boston brown bread	1 slice ½" thick
Bran muffins	1½
Cornmeal muffins	1 small
Graham bread	1 slice ⅝" thick
Griddle cakes	1
Muffins (white flour)	1 small
Popovers	1½
Waffles	1 section
White bread	1 thick slice or 2 thin slices
Whole wheat bread	1 thick slice or 2 thin slices
CEREALS	
Cornmeal mush	½ to ¾ cup
Cream of wheat	½ to ¾ cup
Macaroni	¾ cup
Rice	½ to ⅔ cup
Rolled oats	½ to ⅔ cup
DESSERTS	
Apple tapioca	⅓ cup
Blanc mange	¼ cup
Blanc mange (chocolate)	¼ cup (scant)
Bread pudding	¼ cup
Brown Betty	¼ cup
Cake (rich)	1 very small piece
Cake (sponge or angel food)	1 medium piece
Cake (lady fingers)	4 medium
Cookies	About 1 (variation great according to richness)
Chocolate soufflé	⅓ cup
Custard (baked)	⅓ cup
Custard tapioca	⅓ cup
Doughnuts	¼ doughnut
Fruit cocktail	½ cup
Fudge	1" cube
Gingerbread	1 small piece
Ice cream (vanilla)	¼ cup
Ice cream (chocolate)	⅕ cup
Ice—orange	¼ cup
Ice—lemon	½ cup
Lemon jelly	¾ cup
Junket	½ cup
Macaroons	2
Pie (apple)	1½" piece
Pie (custard)	1" piece
Pie (mince)	1" piece
Prune whip	⅓ cup
Indian pudding	⅓ cup
Rice pudding	⅓ cup
Sherbet—milk	¼ cup
MEAT SUBSTITUTES	
Baked beans	½ cup
Cheese soufflé	½ cup
Chowder	¼ cup
Creamed dried beef	¼ cup
Creamed codfish	¼ cup
Macaroni and cheese	¼ cup
Oyster stew	½ cup
Salmon loaf	⅓ cup
Welsh rarebit	3 tablespoons
SALAD DRESSINGS	
Boiled dressing	¼ cup
French dressing	1½ tablespoons
Mayonnaise	1 tablespoon
SAUCES	
Chocolate sauce	2 tablespoons
Hard sauce	1½ tablespoons
Lemon sauce	¼ cup
Stirred custard	⅓ cup
Tomato sauce	½ cup
White sauce (thin)	⅓ cup
White sauce (medium)	¼ cup
White sauce (thick)	⅕ cup
SOUPS	
Bean soup	¼ cup
Celery soup	⅔ cup
Corn soup	½ cup
Onion soup	⅔ cup
Pea (fresh) soup	½ cup
Pea (split) soup	¼ cup
Potato soup	½ cup
Spinach soup	⅔ cup
Tomato soup	⅔ cup

From *Your Weight and How to Control It*, edited by Morris Fishbein, M. D. (Doubleday, Doran & Co.)

APPROXIMATE NUMBER OF HUNDRED-CALORIE PORTIONS TO BE ALLOWED FOR DIFFERENT INDIVIDUALS

Individual	Per day	Per week
The average person over 12 years of age	27	200
A man or boy using large amount of muscular energy in work or play	40	280
A man or boy using moderate amount of muscular energy in work or play	33	235
A man or boy using little or no muscular energy in work or play	27	200
A woman or girl using large amount of muscular energy in work or play	33	235
A woman or girl using moderate amount of muscular energy in work or play	27	200
A woman or girl using little or no muscular energy in work or play	22	150
A boy or girl between 10 and 12 years of age	20	140
A boy or girl between 6 and 9 years of age	17	120
A boy or girl between 1 and 5 years of age	14	100
An infant under 1 year of age	6	40

From *Good Proportions in the Diet*, Farmers' Bulletin No. 1313, U. S. Dept. of Agriculture

THE COSMIC RAYS

by
EARLE H. KENNARD, Ph.D.
Professor of Physics, Cornell University

THE discoveries of the last decade in physics have mostly had to do with very small things, namely, the atoms themselves. On the other hand, one of the most interesting lines of research concerns the earth in relation to its cosmic surroundings. Apparently something is bombarding the earth from the outside, and a number of physicists are working hard to find out the nature of this strange visitation from space, to which has been given the name of "cosmic rays."

The cosmic rays are detected by means of the slight electrical conductivity which they produce in insulators and especially in gases such as the air. The nature of the conductivity itself is well understood. A few molecules in the gas are somehow made to lose electrons, thus becoming "ionized," while the electrons in turn attach themselves (except at very low pressures) to other molecules and so ionize them in the contrary sense; then when an electrical field is applied these ions move in the field and form an electric current. The problem, however, is to find out what it is that is knocking the electrons out of the molecules and where it is coming from.

In attacking the problem physicists have naturally looked for the cause among the known ways of ionizing gases in the laboratory. This can be done by passing ultra-violet light or X-rays through the gas; or we may use the "rays" from a radioactive substance such as radium. The rays due to radioactivity are of two fundamentally different kinds; some of them are "gamma-rays" or very short light-waves, like X-rays only much shorter, whereas others consist of charged particles moving at enormous speed, and some of these particles are negative electrons while others are "alpha particles" or doubly ionized helium atoms. In the laboratory we can also produce streams of "protons," that is, ionized hydrogen atoms, moving at high speed, and these likewise constitute a good ionizing agent.

Accordingly the slight conductivity observed long ago in all gases was commonly ascribed to some sort of "rays" similar to those from radioactive substances. The next question was, where are these rays coming from? That they did not come from the walls of the vessel containing the gas was shown by changing the material of which the vessel was made; sometimes the choice of material made a difference, suggesting contamination with radioactive substances, but in general it did not. Do the rays come, then, out of the earth, or perhaps from radioactive emanations suspended in the atmosphere? To test this point, many trials have been made during the past twenty years by observing the ionization under widely different surroundings.

The method of observing the conductivity is a very simple one. An electroscope used for this purpose by Prof. Robert A. Millikan of the California Institute of Technology is diagrammed in Fig. 1. Two fibers F suspended from an insulated support are gently drawn taut by the little bow of quartz wire Z. When an electric charge is put upon the fibers by turning the charging wire W, which is

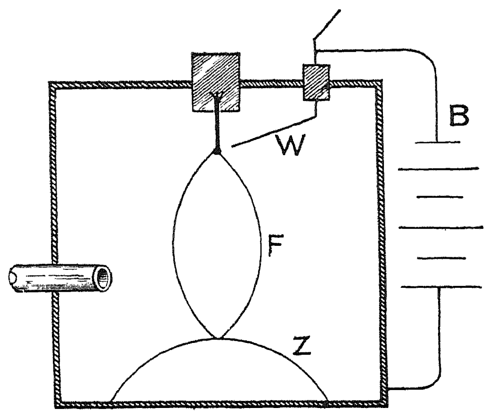


FIG. 1.
Diagram illustrating a simple type of cosmic ray electroscope.

connected to the battery B, momentarily into contact with their support, they repel each other and spread out. Then as cosmic rays penetrate through the walls of the electroscope and ionize the contained gas ions are drawn to the charged fibers and gradually lessen their charge, so that their mutual repulsion decreases and they are drawn closer together by the downward pull of the quartz bow. The rate of this motion, which is observed through a microscope, serves as a measure of the intensity of the cosmic rays. The gas used is frequently argon and its pressure may be raised to 30 atmospheres or more in order to increase the sensitivity of the instrument.

When observations of the intensity of the cosmic rays are made in this manner in a mine or in a tunnel, the values found are sometimes larger than at the surface, due presumably to slight amounts of radioactivity in the surrounding rocks, but in other cases the rays are much weaker than at the surface, as if something had been screened off by the surrounding mass of rocky material. In the hope of getting away still more completely from radioactive sources electroscopes have been lowered under the very pure water of deep snow-fed mountain lakes such as Muir Lake in California or Lake Miguilla in Bolivia. In such cases the ionization is always found to decrease as the depth increases, at first rapidly, then slowly. At 200 feet the rays are only a twelfth as strong as at the surface, but they are still barely detectable at 600 feet.

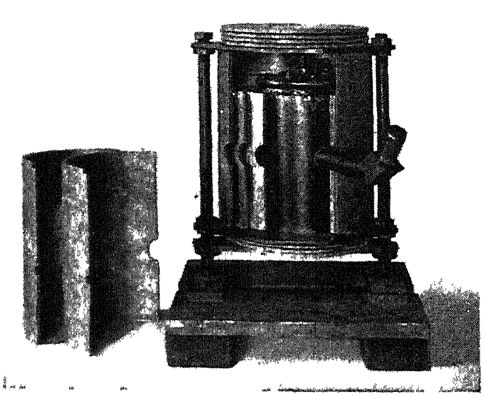


FIG. 2.
First type of Prof. Millikan's Electroscope used in the study of cosmic rays.

Going in the opposite direction, in addition to observations on many mountain tops, observers have taken instruments up in balloons and have found a rapid increase in the intensity. Instruments have also been sent up on unmanned "pilot" balloons to heights as much as 17 miles above the earth's surface. In this latter case the apparatus is modified in that the electroscope fiber is projected upon a photographic film moved by clockwork, the intensity of the rays being calculated from this record after the balloon has descended again and been recovered; a recording barometer and thermometer are also carried on the pilot balloon so that the height to which it ascends can be calculated. With such a balloon the German physicist Regener found the rays at a height of 17 miles to be nearly fifteen times as strong as at the earth's surface. V-2 rockets, equipped with apparatus to detect cosmic rays, have shown that at greater heights than this, the intensity of the rays falls off.

When we consider the different observations that have been described in these pages, it seems clear that cosmic rays must come from somewhere beyond the earth's atmosphere. The theory that they arise in the topmost fringe of the atmosphere has never met with any favor. The sun would be a likely source for cosmic rays, were it not that their strength is practically the same

at all hours of the day or night; and this latter fact also argues against supposing them to come from the stars, since we would then expect them to be strongest when the region of the Milky Way is overhead, with its greater abundance of stars. It must be recognized, however, that this argument loses much of its force if the rays consist of charged particles, for these would be deflected by the magnetic field of the earth and so might even strike its surface on the opposite side from the celestial body out of which the rays originally came.

The question as to the exact nature of these strange rays thus becomes an important and fascinating one. Their penetrating power is astonishing in comparison with anything known in the laboratory. Whereas the larger part of them as they enter the earth's atmosphere are soft enough to be stopped by a mile or two of air, those that reach the earth's surface, after passing through the equivalent of 34 feet of water, are only half absorbed by an additional 6 feet of water, and the small portion that is "hard" enough to penetrate several hundred feet below the surface of a lake are only half absorbed by an additional 120 feet of water or 12 feet of lead, or are 90 per cent absorbed by 400 feet of water or 35 feet of solid lead. For comparison it may be stated that a foot of lead stops 90 per cent of the gamma rays from radium, and a thirtieth of an inch of lead stops at least 90 per cent of the rays from most X-ray tubes.

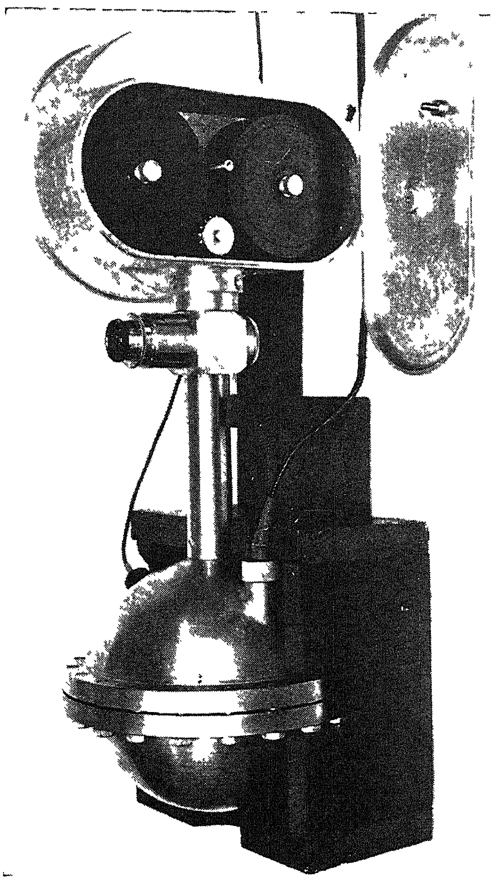


FIG 3.
Dr Victor Neher's modification of Prof. Robert A Millikan's Electroscope This is an automatic, self recording instrument, which has the quality of being "vibration free" and therefore gives as accurate a record in an airplane or a railway train as in a laboratory, and has therefore made it possible to extend the accuracy of observation heretofore obtained only on earth to as great heights in the atmosphere as can be reached with airplanes or balloons Photo California Institute of Technology.

Such high penetrating power suggests immediately the hypothesis that the cosmic rays are ether or light waves, like the gamma rays from radium only very much shorter in wavelength. According to the best theory that we have their wavelength, if they are waves, should be something like a trillionth of an inch as against a hundred-billionth or so for gamma rays and a fifty-thousandth of an inch for visible light waves.

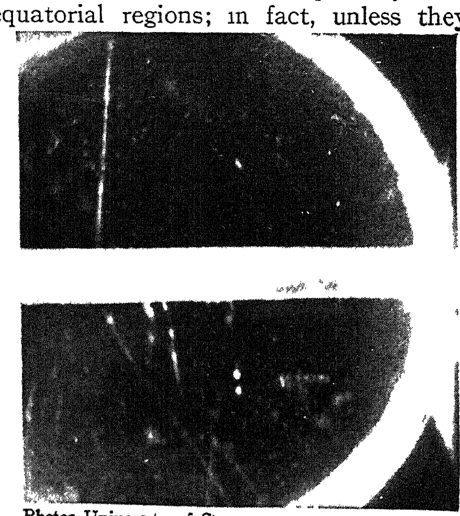
It has been suggested that such waves might be emitted in the process of combination of simpler atoms into more complex ones. According to present theory it ought to be possible under suitable circumstances for four atoms of hydrogen to unite into one atom of helium with the loss of a certain amount of energy, and if this excess energy were radiated away as one "quantum" it would have a wavelength corresponding pretty well to the softest cosmic rays that reach the earth's surface. Other harder constituents in the rays have been ascribed by Millikan to the formation of silicon and of iron. It is, however, rather hard to understand just where in the depths of space such atoms can be undergoing formation in sufficient numbers to account for the observed intensity of the rays. It must be only very

rarely that four atoms of hydrogen meet in just the right way so that they will "click" together into a helium atom; such an occurrence is not, of course, known in the laboratory. The most likely place for such occurrences seems to be in the interior of stars, where there are some reasons for believing that temperatures up to several million degrees may occur and the behavior of matter may be very different from that with which we are acquainted on the earth. This suggestion encounters, however, the difficulty mentioned above that the cosmic rays seem to come equally from all directions in space.

An alternative possibility is that the cosmic rays may consist, so to speak, of "ionic meteors," that is, charged particles of some sort moving at tremendous speed in all directions through space, probably either electrons or protons. Now this hypothesis can be tested by studying the geographical distribution of the rays over the earth. For particles carrying an electric charge should be deflected by the earth's magnetic field, which must extend out many thousands of miles from its surface. It can be shown that the particles would thereby tend to be kept away from equatorial regions; in fact, unless they have energies exceeding a certain minimum they could not reach the earth's surface near the equator at all.

A very extensive series of observations to test this point was organized in 1930 by A. H. Compton of the University of Chicago. Observations were made at sixty-five different places, including stations on the Andes and at sea level in Peru, in South Africa, Switzerland, Lahore (India), Spitsbergen and New Zealand. The results of all these observations indicated that the cosmic rays actually are weaker in a belt extending to 20° on each side of the magnetic equator than they are at distances exceeding 50° from this equator (which swings 10° north of the geographic equator in Siam and 10° south of it in Brazil). The difference in intensity amounts to 14 per cent at sea-level and increases to 33 per cent at a height of 15,000 feet.

According to theoretical calculations, based upon the known magnetic field of the earth, a distribution of this sort is explained if part of the rays consist of electrons moving with the colossal energy of 7,000,000,000 electron volts. The rays that reach the surface in equatorial regions may be electrons moving with energies exceeding 20,000,000,000 volts.



Photos University of Chicago

FIG 4a

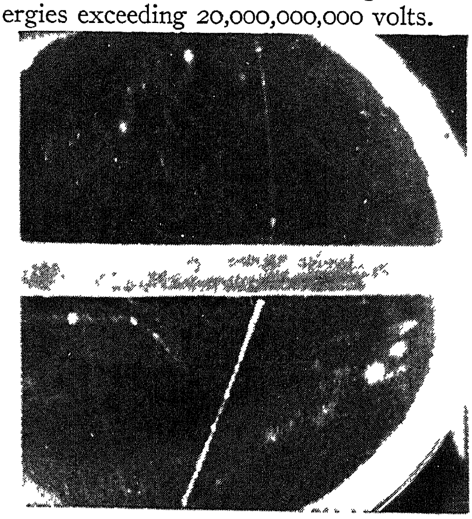


FIG. 4b

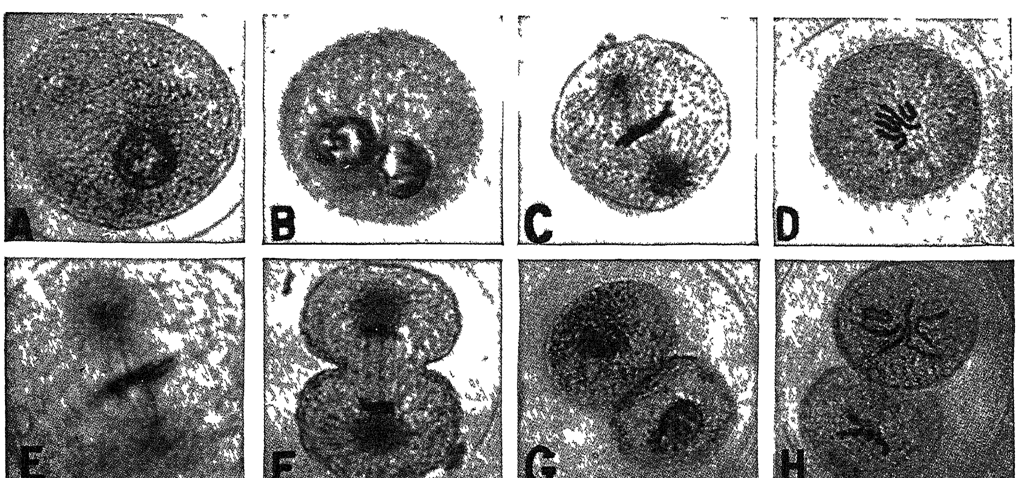
When mesotrons pass through a chamber containing moisture on the point of condensation, they leave droplets of water in their path which can be photographed, as shown above. The barrier in the center is a lead plate, but mesotrons can easily penetrate this plate Figure 4a shows a slow mesotron entering and disintegrating in the lead plate, giving rise to an electron. Figure 4b shows a mesotron losing energy in passing through the plate, ionizing more heavily as it comes out.

CHROMOSOMES

The Bearers of Hereditary Characteristics

THE bridge that connects two successive generations of living beings reproducing their kind by differentiated eggs and sperm is narrow. It consists of the microscopic germ cells — the egg of the mother and the spermatozoön of the father. The former is so small that, as someone has calculated for the human type, fifty thousand could be sent across the country for the price of a three-cent stamp. Even so, it is much larger than the contribution of the father. Yet all the characteristics that the father possesses and that reappear in the son must pass over this bridge. Moreover, the portion of the bridge that is used for traffic — which actually bears the hereditary qualities — is still more restricted, being only material of the central nucleus of the cell. This appears at certain times in the form of minute rods called chromosomes, which are less, often much less, than one thousandth of an inch in length. The total hereditary endowment of the individual is contained in these tiny rods. But though very small, they may be very important, just as, in external inheritance, a small document that a father bequeaths to his son may be worth great sums of money.

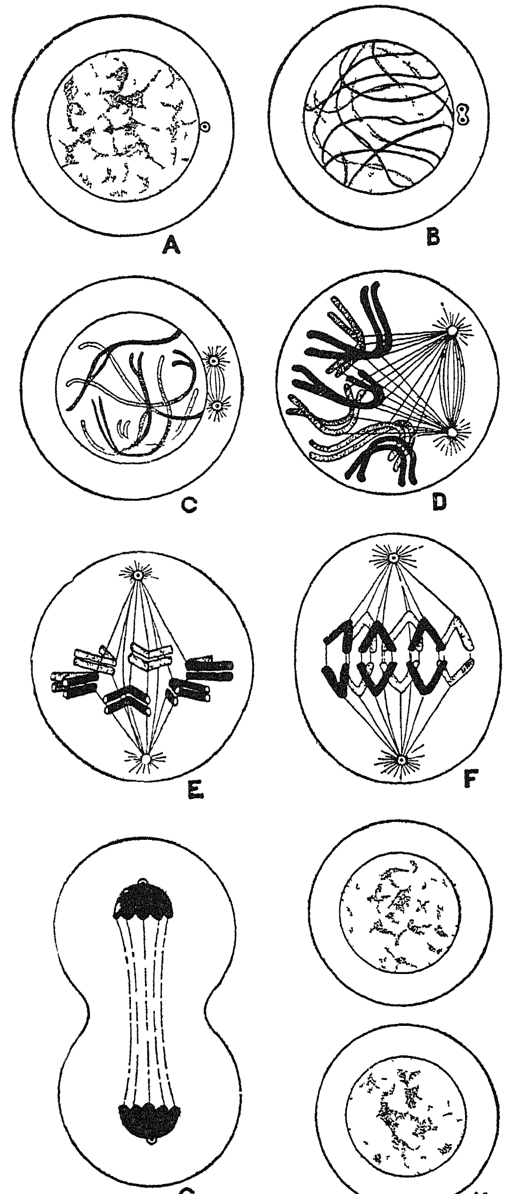
Every individual animal, plant or human being begins life as a single cell, the egg. A photograph of an animal egg at a magnification of several hundred times may be seen at the upper left of our first illustration. The denser nucleus is surrounded by a cell plasm (cytoplasm). The nucleus of the male germ cell enters this cytoplasm, and immediately the two nu-



From Haldane and Huxley's PRINCIPLES OF ANIMAL BIOLOGY, the Clarendon Press, Publishers

Figure 1. These photomicrographs, at magnifications of about 500, show the behavior of the chromosomes during the successive stages of fertilization and division of an animal (the round worm). A is the unfertilized egg with its dense nucleus. B shows male and female nuclei with their material in long thin threads. C shows the line of chromosomes from the side and D from above. In E the chromosomes are splitting. In F the two groups are moving to either end and the cell is constricting. In G two daughter cells have been constituted. These cells are in turn undergoing division in H.

clei, male and female, resolve their material into long, thin, coiled threads (second figure of first illustration). These threads



From Babcock and Clausson's *Genetics in Relation to Agriculture* McGraw-Hill Book Co, Publishers

FIGURE 2.—Diagrammatic representation of the successive stages in cell division involving the splitting of the chromosomes, and the separation of their halves to the daughter cells

then break up into pieces which are the chromosomes, two in number for each nucleus of the species photographed. The chromosomes then move into a line across the middle of the cell and each one splits lengthwise into exactly equal halves. The two halves of each one separate and move to opposite ends of the cell. Two groups of half-chromosomes may then be seen moving towards the ends of the cell (second photo in lower row, figure 1) Reaching the end, the members of each group join to form a new nucleus. In the meantime a wall forms across the center Consequently there are now two properly constituted cells where at the start there had been only one In this way a two-celled embryo is produced from the fertilized egg And owing to the manœuvres and splitting of the chromosomes, each daughter cell receives half of every particle of chromosome material contributed by both the father and the mother.

After a period of rest and growth each daughter cell divides again. The same series of manœuvres is repeated The same number of chromosomes appear in the same form and size as before, and undergo the same movements and splitting A clearer view of the successive stages than can be obtained from photographs is shown in our second illustration. This is a diagrammatic representation of cell division in a species which has six chromosomes By this process the two daughter cells of the fertilized egg become four cells, and it is clear that each of the four receives a representative of every particle of the original maternal and paternal nuclei. The process is repeated until the billions of cells which make up the adult body have been formed. Development consists of the multiplication of cells by the division of those already in existence Between successive divisions each daughter grows to normal size. And eventually, of course, they differentiate into muscle cells, nerve cells, and so forth, or, in the plant into wood, cork, and so forth.

Owing to the nature of the division it is clear that every cell in the body receives a direct descendant of every chromosome originally contributed by the mother and by the father. The most impressive thing about cell division is the extraordinary care which nature takes to ensure that every

particle of nuclear matter is equally divided between the daughter cells. Obviously, every particle is necessary for the proper functioning of every cell. In fact, the particles of chromosome material are the determiners of hereditary characters.

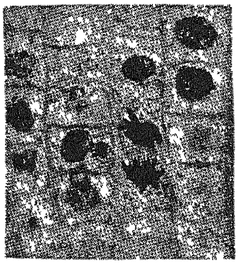


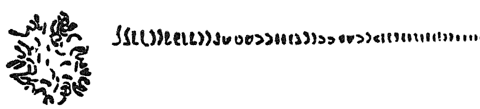
FIGURE 3—Photomicrograph of cells from a growing root. One cell is in the last stages of division, the two groups of chromosomes about to reconstitute the daughter nuclei

The chromosomes are definite organs of the cell, each with its own individuality. They appear in exactly the same number at every division in every individual of a species (with certain minor exceptions), though the number varies from species to species.

FIGURE 4—The four pairs of chromosomes of the fruit fly, each pair different from the others

Thus human cells always have forty-eight, those of the common wheat forty-two, the lily twenty-four, the fruit fly eight, the round worm four.

Moreover, in many cases it can be seen that every chromosome always differs regularly from every other in size, shape or other respects. To this statement the important exception must be made that for every chromosome in a body cell there is one exactly similar. In other words the chromosomes are in pairs. Thus the eight of the fruit fly are really four pairs (figure 4). The two members of a pair are exactly alike but different from every other pair. They are usually not paired in position but in form, size, etc. Similarly the forty-eight of man really consist of twenty-four pairs. This is difficult to see as they occur jumbled up, but when they are drawn in a single row according to size it becomes

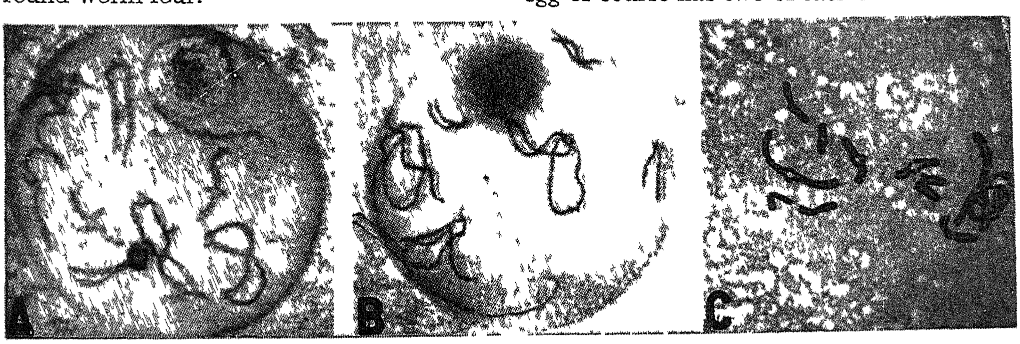


From *Eugenics in Race and State*, Williams & Wilkins, Publishers

FIGURE 5—The forty eight chromosomes of man, at the left as they actually appear, at the right drawn separately to show the pairs and their individuality

evident (figure 5). In cases like the human, in which the number is large, it may be difficult or impossible to distinguish all the pairs, but in most cases some of them can be recognized like old friends at every division.

The reason for the paired condition is that one member of each pair has been contributed by the father and the other by the mother. The egg and sperm each have only one member of each pair, and since they fuse at fertilization, the fertilized egg of course has two of each kind or twice



Courtesy of *Journal of Heredity*

FIGURE 6—The mating of the chromosomes in pairs preceding the formation of reproductive cells. The members of a pair become closely associated to form a single bivalent chromosome. In the photograph at the right the double nature of each is still evident.

as many altogether. And all the millions of cells derived from the fertilized egg must also have two of each kind, one of maternal origin and one of paternal.

Each minute packet of hereditary determiners retains its characteristic individuality throughout the numerous complex divisions which build up the body. And eventually, when each determiner finds itself in the appropriate position, it proceeds to bring about the expression of the characteristic for which it is responsible.

In ordinary cells the two partners constituting a pair pay no particular attention to each other, the whole set being apparently mixed up haphazard. But when the reproductive cells for the next generation are about to be formed, they suddenly reveal their affinity. The partners, one maternal and one paternal, come into intimate association. They move into position alongside each other, twist about each other (figure 6) and eventually fuse to form a single chromosome of double size. The cell which is to give rise to reproductive cells therefore appears to have half as many as ordinary cells. The double-size chromosomes line up and divide, the division really consisting of the separation of the two partners which had previously mated. Each reproductive cell will therefore have only half as many chromosomes as the other cells but will have one member of each pair (figure 7). And this is the condition with which we started in the reproductive cells of the parents.

We have now traced the behavior of the chromosomes throughout the life cycle. A synopsis of the whole remarkable story is presented graphically in our diagram (figure 8). The fertilized egg receives one member of each pair from both egg (black) and sperm (white), and therefore has two of each kind. Owing to the way in which it divides and in which all other divisions occur, every cell in the body has a similar double set. Previous to the formation of the reproductive cells in this body, the partners mate, and then separate, so that each reproductive cell receives only one member of each pair (lower half of figure 8), but may receive a mixture of maternal and paternal origin. The whole drama is repeated generation after generation with the utmost regularity, in spite of the diminutive size of the actors.

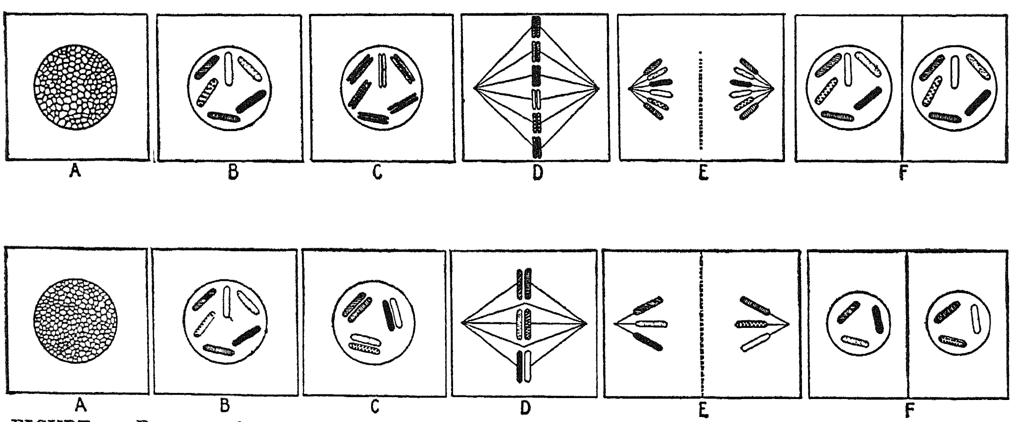


FIGURE 7.—Diagrams showing the difference between successive stages in an ordinary cell division (upper row) and one involving mating of the chromosomes (lower row). Note particularly C, D and E.

The behavior which has been outlined is of the greatest importance in heredity and breeding. It is, in fact, responsible for the laws of heredity. Suppose one parent has blue eyes and the other brown, or one is a beardless wheat and the other bearded. Each of the contrasted conditions is represented by a particle in a certain chromosome (in our diagram by A and a). It is evident that both will be present in every cell in the body of the offspring. Which condition will appear, or whether the offspring will be intermediate, depends on Mendelian dominance. Then when the reproductive cells are to be formed, since the chromosome containing "A" mates

with that containing "a" and the two then separate to different daughter cells, it is clear that both can never go into the same reproductive cell. *Now the inability of factors for contrasted characters to enter the same reproductive cell is Mendel's first law of heredity.* Mendel worked out his law from the breeding results alone. He never heard of chromosomes. They were first described the year before he died, and long after he had announced his law. But chromosome behavior shows why his law is of universal application. It could have been predicted at any time after the story of the chromosomes had been pieced together.

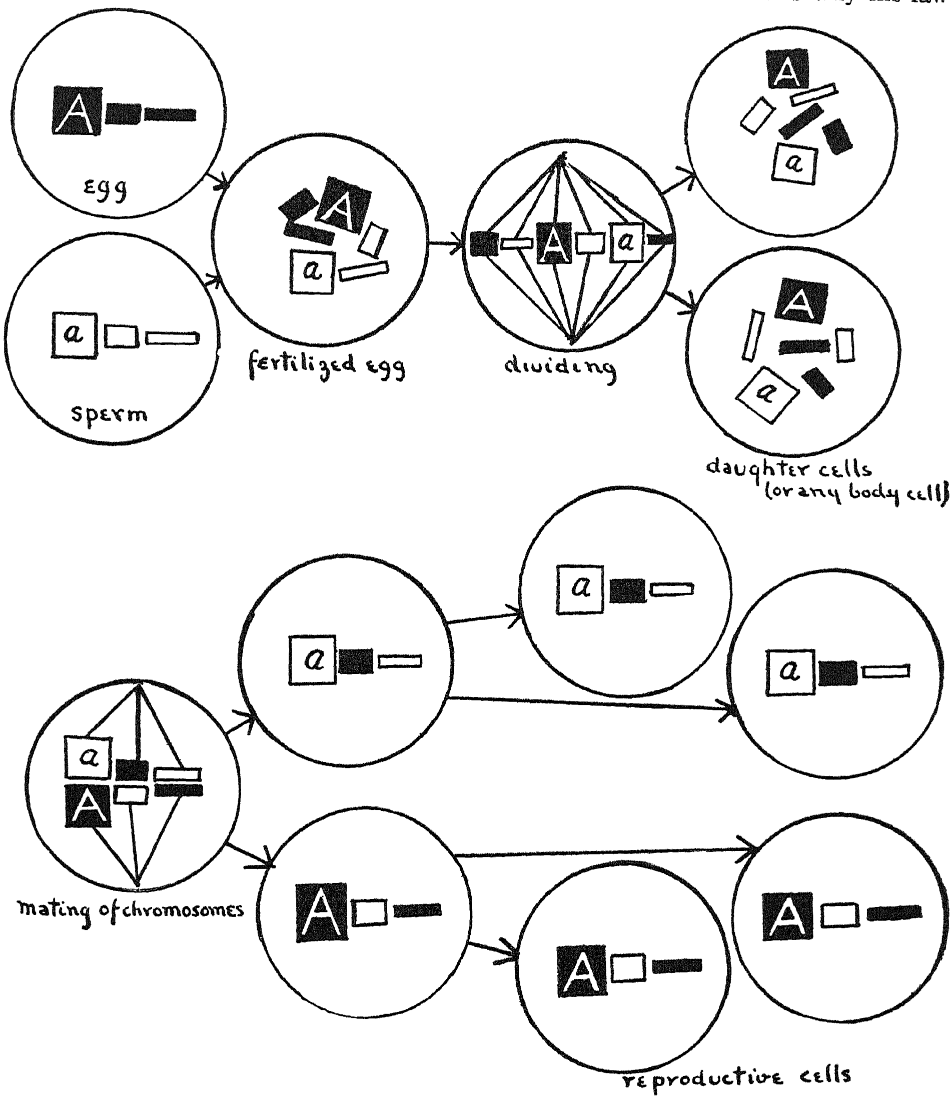


FIGURE 8.—Behavior of the chromosomes through the life cycle. Millions of divisions occur between the stage represented at the end of the first row and that at the beginning of the second. A and a represent factors (genes) for a pair of contrasted hereditary characters Their segregation to different reproductive cells (lower row) is the essence of Mendelism.

The other laws of heredity depend equally on chromosome behavior. Mendel's law of independent assortment of characters must follow if two or more pairs of contrasted characters are determined by factors in different pairs of chromosomes. Linkage of characters is due to the location in the same chromosome of the factors for the linked characters.

Each chromosome is a packet of determiners of hereditary characters. Each determiner, called technically a "gene", is apparently a definite chemical entity. Recent work has demonstrated that these genes are arranged in a single row along the chromosome, and that the arrangement is regular and constant. In fact, one of the most astonishing achievements of modern biology has been the determination of the exact position of hundreds of genes in the chromosomes of certain species. For example, it is now actually possible to draw

FIGURE 9.—Photographs, at magnifications of 1,000, of chromosomes of three different species of wheat, A with 7, B with 14, C with 21.

maps of all the chromosomes of the fruit fly, and to mark on those maps the location of hundreds of different determiners of hereditary characteristics.

The conditions and behavior of the chromosomes also throw much light on problems of evolution. In many cases a significant relationship is found among the chromosome numbers and forms in related kinds of organisms. For example, the ten or more distinct species of wheat fall naturally into three groups. Those in group 1 have fourteen chromosomes in all their body cells; those in group 2 have twenty-eight; and those in group 3, which includes our common bread wheats, have forty-two. The reproductive cells have half these numbers, i.e., seven, twice seven, three times seven (figure 9). It is believed that a common ancestor had seven and that the evolution of the different species of wheat has involved the duplication and triplication of chromosome sets. Though our bread wheats all have twenty-one chromosomes (in reproductive cells) certain species with fourteen have desirable qualities such as rust and drought-resistance, which would be very valuable in ordinary varieties. But numerous attempts to combine the desirable qualities of the two have failed because of the difference in chromosome number. This upsets all genetic rules because some of the chromosomes have no mates.

The roses present a very interesting situation from the standpoints both of chromosomes and evolution. More than one thousand species have been studied and all have chromosome numbers which are multiples of seven. Nearly four hundred species have fourteen (in the body cells), while the remainder have twenty-one, twenty-eight, thirty-five, forty-two, or fifty-six. Furthermore, it has been established that in the whole genus of roses there are five different sets of seven chromosomes. If these five sets be designated A, B, C, D and E, the chromosome formulæ for different species may be written AAAA, BBBB, AABB, AABBCC, BBEE, etc.

The majority of large genera of plants have their species with chromosome numbers in such multiple series. In some cases all the species in a genus belong in one series; in others two series with different basic numbers run through the genus; in others some species are in series and the rest not. It is clear that multiplication of chromosome sets and hybridization with the consequent association of different sets have played a big part in the evolution of plants. In other cases evolutionary change has involved the duplication or loss of individual chromosomes. In animals such changes in chromosome numbers have not played so conspicuous a part. Nevertheless, the chromosome complements of related animal species often show significant relationships of size and form.

Science and Progress (1815-95) V

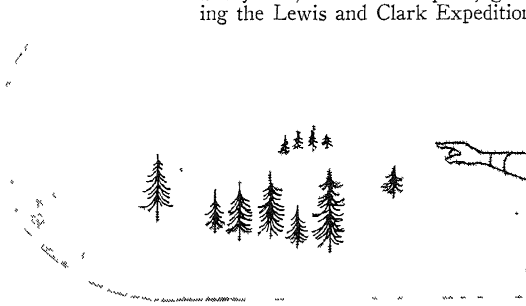
by JUSTUS SCHIFFERES

NEW VOYAGES OF DISCOVERY

THE daring sea voyages of the fifteenth and sixteenth centuries were undertaken primarily to discover new lands and found new empires. With certain notable exceptions, the overseas and overland expeditions of the seventeenth and eighteenth centuries were sent out to establish colonies or to convert native peoples or to find new sources of raw materials. In the nineteenth century, a number of exploring expeditions were launched, after careful preparation, with the express aim of adding to man's knowledge of the globe he inhabits. Vast areas of North and South America and Africa, to say nothing of the sea bottom and the Arctic and Antarctic regions, were revealed to mankind. These expeditions, undertaken without thought of immediate gain, often opened up unexpected natural resources, which later were fully exploited.

During the nineteenth century, the continent of North America was more thoroughly explored than any other; by the end of the nineteenth century, its vast expanses had been quite accurately mapped. The man who touched off this great movement of exploration was America's famed scientist-president Thomas Jefferson. On April 30, 1803, the United States had acquired by purchase from the Emperor Napoleon a vast region called Louisiana, extending from the Mississippi to the Rocky Mountains and from Mexico to the Lake of the Woods. President Jefferson decided to send out an expedition to explore this vast new addition to the fledgling republic.

As leader of the expedition, he selected his one-time private secretary, Captain Meriwether Lewis (1774–1809), who



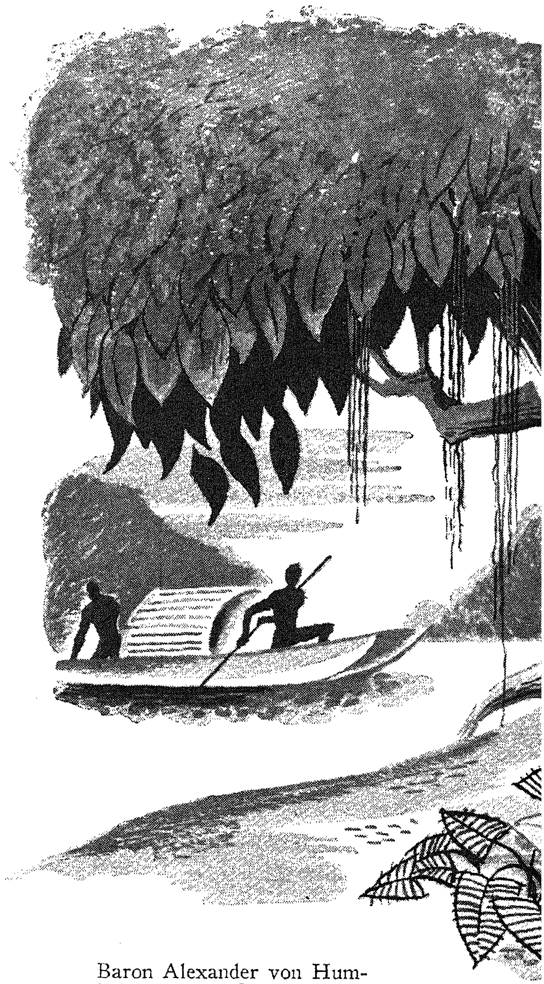

Sacajawea, an Indian squaw, guiding the Lewis and Clark Expedition.

hailed from Albemarle County, Virginia. Lewis chose as his second-in-command Lieutenant William Clark (1770–1838), also a native Virginian but then residing in Kentucky. These two men organized the Lewis and Clark Expedition whose purpose was, in Jefferson's words, "to trace the Missouri to its source, to cross the highlands [that is, the Rocky Mountains] and follow the best water communication from thence to the Pacific Coast."

The trip down the Ohio, up the Mississippi and then up the Missouri to its Great Falls was accomplished by means of river boats and canoes with much labor but little danger. In April 1805, Lewis and Clark sent sixteen of their men back down the Missouri by keelboat with specimens, gifts for the President and careful accounts of what they had already seen and what they had learned from the Indians.

The party that went on included, in addition to its leaders, twenty-six soldiers and rivermen; Clark's Negro servant York, an amazing sight to the Indians, who had never seen a black man before; two French hunters and the Indian wife and half-breed papoose of one of them. The Indian squaw, Sacajawea, a remarkably intelligent woman who acted as guide and interpreter, was as much responsible as anyone for the success of the expedition. She was familiar with the territory between the Missouri and Columbia rivers, for she had been a member of a Shoshone tribe that had dwelt in this area.

The expedition passed the Three Forks of the Missouri, above Great Falls; then the explorers obtained horses from the Indians and crossed over the Great Divide. At last they came to the Columbia River, teeming with salmon. They sailed down the river and in November 1805 reached the Pacific Ocean where the Columbia empties its waters. The return journey was made by the same route the next year. The information that Lewis and Clark brought back about the Great Northwest encouraged fur trading and then settling in this region. Within a single generation the Oregon Trail rivaled the Santa Fe Trail as a road to the West.



Baron Alexander von Humboldt, famous German naturalist, traveler and statesman, exploring the Orinoco River.

Lewis and Clark were not the first white men to reach the Pacific by the land route; they had been anticipated by a young fur trader, Alexander Mackenzie (1755?–1820), in the employ of the Northwest Fur Company. This venturesome young man had journeyed by canoe in 1789 from Fort Chippewyan along the Great Slave Lake and down the river that now bears his name to the Arctic Ocean. In 1792–93, Mackenzie made an overland journey from Fort Chippewyan to the Pacific coast near Cape Menzies. At the top of a large rock bluff overlooking Vancouver Bay, Mackenzie wrote in red grease paint an inscription, since chiseled in the rock, which summed up his achievement:

"Alexander Mackenzie, from Canada, by land, the twenty-second of July, one thousand seven hundred and ninety-three."

The interior of North America was explored by fur traders like the famous Missouri Legion, by Indian scouts like Kit Carson and by religious exiles like the Mormons; it was mapped and surveyed by railroaders and geologists. A journey "unequaled in the annals of geographical exploration for the courage and daring displayed in its execution" was made in the summer of 1869 by an American geologist, John Wesley Powell (1834–1902), who later became the director of the United States Geological Survey. He termed his magnificent adventure a "modest boat trip down the Colorado [River]"; as a matter of fact, it was a hazardous feat that has seldom been repeated. Powell explored the cavernous depths of the Grand Canyon. He reported that two great natural agencies had sculptured the face of the valley of the Colorado and the Southwest in general; these agencies were the upheaval of land masses and the erosion of their surfaces. Control of erosion, particularly of topsoil, remains a vital problem today.

There were also notable explorations of South America in the nineteenth century. No man did more to reveal the mysteries of the continent than the German naturalist, traveler and statesman Baron Alexander von Humboldt (1769–1859).

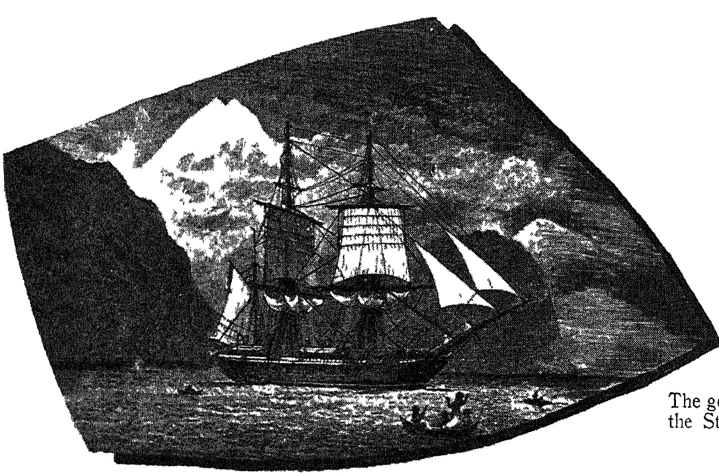
This versatile man, a Prussian by birth, was educated at Goettingen, Freiberg, Frankfurt and Berlin. His early travels took him to Belgium, Holland, England and France. They served as a fitting prologue to his notable five-year trip of exploration to South America.

In the year 1799 he set out on this famous trip aboard the Spanish frigate Pizzaro, with the French botanist Aimé-Jacques-Alexandre Bonpland as his companion. In the course of the five years that followed, Humboldt thoroughly explored South America: its rivers, its mountains, its plants, its skies, its people. The luxuriant vegetation fascinated him; the strange animals and sea creatures fired his imagination. "Even the crabs are sky-blue and gold!" he exclaimed. He followed the course of the Orinoco through tropical jungles, and he established its connection with the upper Amazon. He crossed the Andes four times, exploring the interior of Ecuador and Peru. At length he returned to Europe by way of Mexico and the United States. He was welcomed back to Europe with joy and enthusiasm. He had been gone so long that his friends had given him up for dead.

Upon his return Humboldt settled in Paris and began a notable career as a writer and lecturer on scientific subjects. He soon became one of the most famous men in Europe. He penned a narrative in French of his journey up the Orinoco under the title of VOYAGE TO THE EQUINOCTIAL REGIONS OF THE NEW CONTINENT; he also wrote a series of technical books on climate, temperature and plants, mostly in French or Latin. In 1827, he reluctantly returned to Germany at the bidding of his royal master, the King of Prussia. Two years later, at the age of sixty, he launched upon his last great journey — a nine-thousand-mile jaunt through the Ural and Altai mountains of Asiatic Russia.

Humboldt spent the last years of his life in Berlin, receiving visitors, exchanging correspondence with the great of the world and writing his most ambitious work, called THE COSMOS. This work, in five volumes, was published from 1845 to 1862 (the last volume appeared after his death). It sought to provide an accurate and complete description and a unified conception of the entire physical world. Understandably it has become outmoded in many respects; yet it remains a superb monument to a great man.

Humboldt's contributions to science were many and lasting. In the course of his travels he accumulated a great mass of geographical data. He discovered the cool current that sweeps up the west coast of South America from the Antarctic Ocean and that now bears his name. He climbed mountains to prove that temperature decreases with height above sea level. He pointed out that the very nature of plants and animals is controlled by the climate and terrain they inhabit. He studied the origin of tropical storms and the changes in the



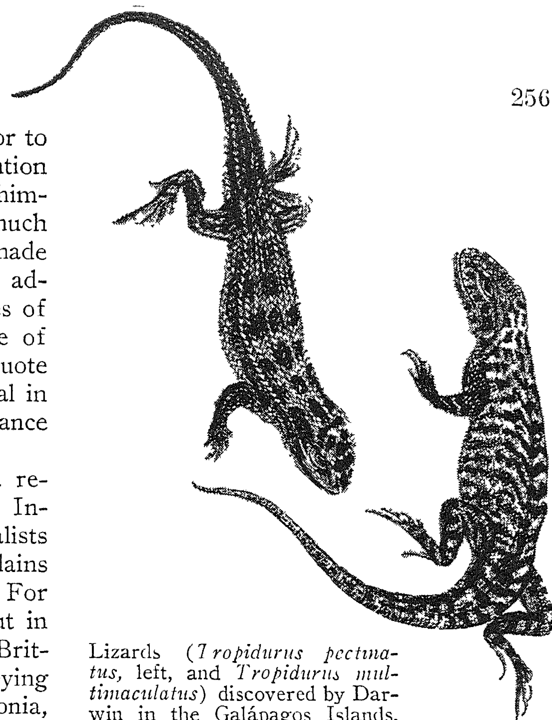
The good ship Beagle in the Strait of Magellan.

earth's magnetic force from the equator to the poles; he also devoted much attention to "magnetic storms," a name that he himself coined. Meteorology became a much more exact science in his hands. He made an intensive study of volcanoes; he advanced the theory, still held, that zones of volcanic activity follow a definite line of cracks in the earth's crust. To quote Goethe, Humboldt was "without a rival in extent of information and acquaintance with existing sciences."

Humboldt's writings provoked a renewed interest in scientific exploration. Inspired by his example, many naturalists now betook themselves to the vast plains and tall mountains of South America. For example, a British expedition, sent out in 1831 in the small ship Beagle, of the British Navy, did important work in surveying various areas of the continent: Patagonia, Tierra del Fuego, Chile and Peru. The Beagle also explored many islands of the Pacific and Atlantic. Young Charles Darwin, who, as we shall see, was destined to stir up the greatest scientific controversy of the nineteenth century, traveled aboard the Beagle as "naturalist."

After the close of the Napoleonic Wars, Britain turned her attention to the exploration of Africa, called the Dark Continent because comparatively little was known about it. British explorers discovered Lake Chad and the mouth of the Niger, and explored the regions between Lake Chad and Timbuctoo. Protestant missions were organized on the Guinea coast in South Africa and in the dominions of Zanzibar. The missionary David Livingstone (1813–73) crossed the Kalahari Desert from north to south in 1849. In the years that followed he traversed the African continent from the west to the east; in the course of these wanderings he discovered Victoria Falls (1855).

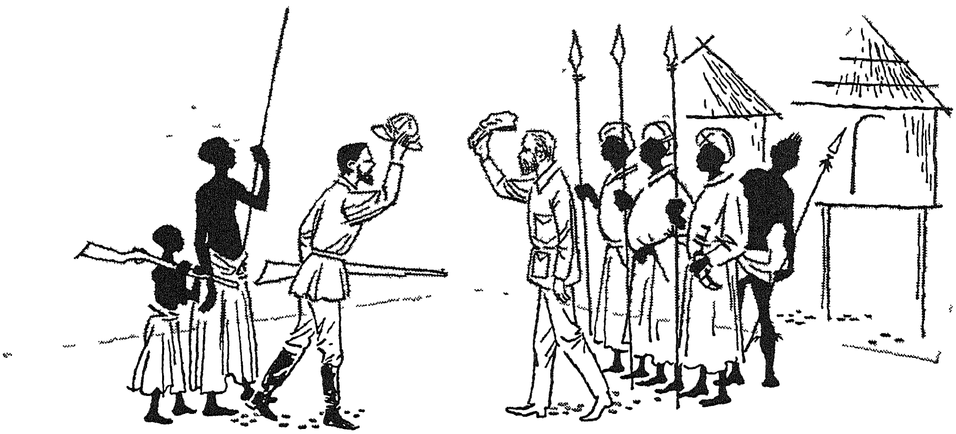
In 1866 he set out on his last journey of discovery. After a time the world lost all trace of him. James Gordon Bennett, the fabulous managing editor of the New York HERALD, interested himself in the matter; he sent out the British-born reporter Henry Morton Stanley (1841–1904), born John Rowlands, to find the famous missionary-explorer. Stanley came upon Livingstone in Ujiji in 1871 and uttered the memorable salutation, "Dr. Livingstone, I presume." Livingstone continued his explorations in Stanley's company for a time; he went on alone after the newspaperman's departure. At last, worn out by disease and fatigue, he succumbed in 1873. In the following year, Stanley explored the Congo River.



Lizards (*Tropidurus pectinatus*, left, and *Tropidurus multimaculatus*) discovered by Darwin in the Galápagos Islands.

Other Englishmen made notable discoveries in Africa. In 1862 John Hanning Speke (1827–64) proceeded along the river that flows from Victoria Nyanza (Lake Victoria) and, following it into Egypt, answered once and for all the age-old question, "Where does the Nile obtain its waters?" Another explorer of the mighty Egyptian river was Samuel Baker (1821–93), who discovered Albert Nyanza, the principal western reservoir of the river. Portuguese, Germans, French and Italians also made notable explorations in Africa. By the end of the century much of the mystery of the Dark Continent had been dissipated.

In the nineteenth century, the British made many surveys of their vast possessions in India. One of these surveying



STANLEY AND LIVINGSTONE

expeditions resulted in the most important development in geology since the time of Hutton. This was the theory of isostasy. It resulted from a survey undertaken in 1823 by Sir George Everest (1790–1866), the man for whom the tallest peak in the world — Mount Everest — is named.

Like all surveyors, Everest used a plumb line to level his instruments. According to the theory of gravitation, the plumb line, wherever it is used, should point directly to the center of the earth It was soon observed, however, that the direction of the line in northern India was different from its direction in southern India. This deflection was attributed to the gravitational attraction of the nearby mass of the Himalaya Mountains. Joseph Pratt (1811–71), a British clergyman and mathematician who spent many years in India as Archdeacon of Calcutta, set out to examine the deviation of the plumb line. He found that the line was attracted far less by the overwhelming mass of the Himalayas than had been expected.

The explanation of this phenomenon was offered by George Biddell Airy (1801–92), English Astronomer Royal and President of the Royal Society. He held that the Himalayas are made up of comparatively light rock, while the plain of the Ganges, to the south, has a denser rock structure. Hence the deviation of the plumb line in the direction of the Himalayas is not so great as it would be if the mountains and the plain had the same density. Airy also advanced the idea that the tablelands and mountains of the earth rest upon a mass of lava. "It appears to me," he said, "that the state of the earth's crust lying upon the lava may be compared with perfect correctness to the state of a raft of timber floating upon water."

According to Airy, the mountains of the Himalayan range and the plains of the Ganges, as well as heights and depressions all over the world, press down upon the underlying sea of lava. They are in balance because the lower-lying lands are heavier than the peaks and mountain ranges. This is the theory of isostasy, or general equilibrium in the earth's crust. The name "isostasy" was first applied in 1889 by the American geologist and army officer Clarence Edward Dutton.

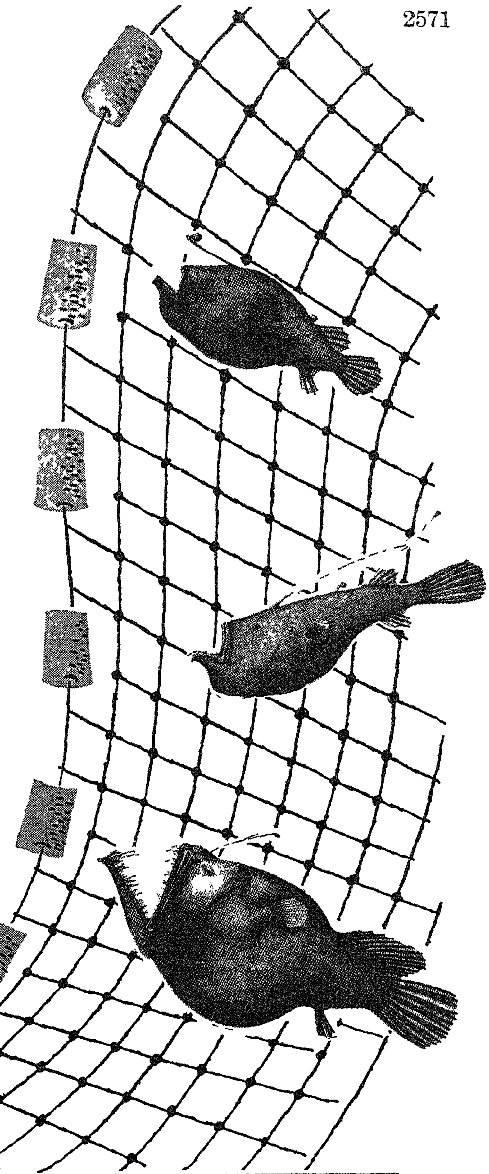
The British took the lead in exploring the depths of the ocean with the famous Challenger Expedition. The Challenger, a wooden corvette of 2,306 tons, was fitted out by the British Navy, "at a cost no more than that of keeping the vessel in commission," for the purpose of exploring the open ocean in every quarter of the globe. Much of the credit for inspiring the voyage of the Challenger belongs to the scientific director of the expedition, Professor Charles Wyville Thomson (1830–82) of the University of Edinburgh.

The Challenger, Captain G. S. Nares commanding, left Portsmouth jetty on December 21, 1872, with a full complement of scientists on board. The route was south

to Madeira, thence to the Canaries, the West Indies and north as far as Nova Scotia; south again to Cape Verde, to the Cape of Good Hope, Australia, the China Sea, Japan, along the west coast of South America, through the Strait of Magellan and back to England. When the ship finally dropped anchor at Spithead, England, on May 24, 1876, it had logged 68,890 nautical miles.

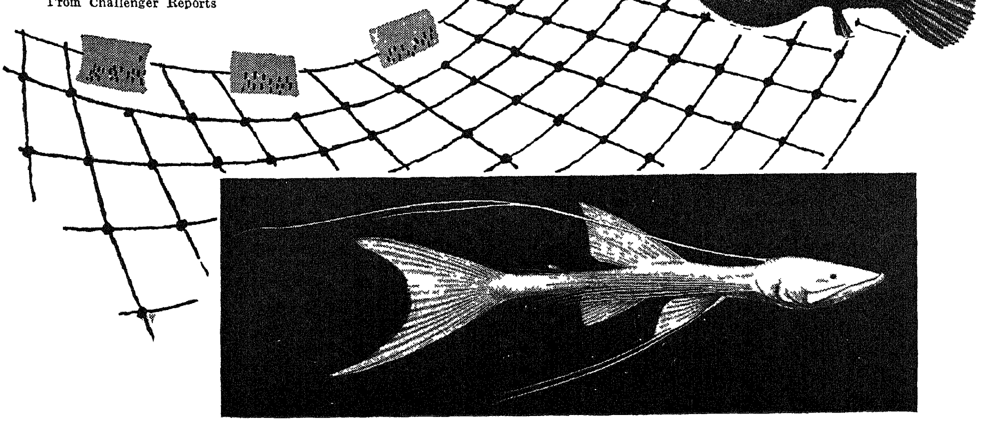
The scientists aboard the ship — "philosophers," the bored naval officers called them — were particularly concerned with what they might find at the bottom of the sea. As a result, they laid the foundations of the modern science of oceanography, which seeks to solve the riddles of the deep. The birthday of this science, according to J. Y. Buchanan, one of the Challenger's scientists, was February 15, 1873, when, forty miles south of Tenerife, the ship took the first of its 362 official "stations." A dredging bucket, suspended on ropes, was lowered into 1,890 fathoms of water to see what could be dragged up from the bottom of the ocean. The temperature of the water at different depths was also recorded The mud from the bottom of the sea proved cold enough to chill a bottle of champagne.

The Challenger Expedition was fruit-



Four deep-sea fishes that were first revealed by the Challenger Expedition From top to bottom *Ceratias carunculatus, Ceratias uranoscopus, Melanocetus Murrayi, Bathypterois longicauda.*

From Challenger Reports



ful indeed. Through numerous analyses of samples, it established the chemical composition of sea water throughout the globe. It made the first comprehensive analysis of the sea bottom. It also exploded a number of myths. It disproved the belief that bathybius, a slimy substance found in the sea, represented vast masses of floating protoplasm. Buchanan showed that this so-called protoplasm is simply a precipitate of calcium sulfate in sea water. The Challenger's scientists also proved that Huxley and others were wrong in supposing that chalk was constantly being laid down on the ocean floor by the shells of tiny sea creatures. Finally, they showed that the "lost continent of Atlantis" — Plato to the contrary — was just not there.

In the year 1880, Thomson issued the first of fifty volumes of Challenger REPORTS, containing an account of the expedition and its findings. Upon his death, in 1882, his brilliant young assistant, Canadian-born John Murray (1841–1914), carried on the publication of the REPORTS, completed in 1895. These reports are still "the indispensable starting points for the study of marine biology." Since the oceans cover so large a proportion of the earth's surface, it is truly amazing that the serious study of its composition and its inhabitants should have been so long delayed.

Explorers of the Arctic and Antarctic

The barren wastes of the Arctic and Antarctic also attracted explorers in the nineteenth century. One of the foremost of these sturdy adventurers was Sir John Franklin (1786–1847), a British naval officer who had served at Trafalgar and the Battle of New Orleans He headed four successive Arctic expeditions, beginning in 1818; the last one, which set out in 1845, never returned. Between 1850 and 1857 his heartbroken wife Jane (nee Griffin) fitted out five ships to search for her husband. At last indisputable evidence was found that Sir John's ship had been deserted and that he and the rest of his party had been lost Jane Griffin Franklin was honored for her services to geographical science by receiving, in 1860, the gold medal of the Royal Geographical Society.

In the last decades of the nineteenth century it became a point of honor among nations to be the first to reach the North and South Poles. England, Norway, Sweden, Austria and the United States all entered the race; many different routes to each pole were explored.

Traveling first by ship and then by dog sled through bitter icy wastes, explorers edged closer to the North Pole, representing the northernmost point of the earth — 90 degrees north latitude. By the end of the century Fridtjof Nansen of Norway and Captain Umberto Cagni, of the Italian Duke of Abruzzi's expedition, had gone beyond the 86th parallel north. It was not until April 6, 1909, that the Pole was finally conquered by the determined American naval officer Robert E. Peary, who had made five previous attempts to reach the goal. The Norwegian Roald Amundsen was the first to reach the South Pole (December, 1911). One month later (January 18, 1912) valiant Captain Robert F. Scott of the British Navy also attained the goal; on the return trip he and his companions lost their lives.

In time the importance of these continuing expeditions became apparent. The northern polar route for air traffic between Europe and America has the most startling possibilities in both peace and war. The weather stations that have been set up in the far north have made weather forecasts more accurate than before. As for the Antarctic regions, they hold immense mineral treasures that some day will add greatly to the world's resources.

Today there are comparatively few regions upon the surface of the globe still to be explored. But science has set up new goals for modern explorers. Armed with microscopes, telescopes, cyclotrons, Geiger-Mueller counters, they seek to ferret out the secrets of the physical universe — the mysteries of the life that fills the earth, of the atoms, of the visible heavenly bodies, of the infinite space that is as yet beyond our ken.

SCIENCE THROUGH THE AGES is continued on page 2694.

THE VITAMINS

The Role Played by Accessory Food Factors in MAINTENANCE OF GOOD HEALTH

ANIMALS, including man, cannot remain in good health on a diet consisting of adequate amounts of the so-called primary food substances alone, namely, *carbohydrates, proteins, fats, salts,* and *water.* Additional food factors commonly designated as *vitamins* or *accessory food substances* are now recognized as being equally essential to normal growth and continued health. In earlier chapters of this series the vitamins have been treated from various angles and interests. Since that time certain fundamental facts have been discovered concerning them and a new era in this field of science is beginning.

Chemical isolation of the specific vitamins has been anticipated as an important step in the progress of our knowledge concerning their rôle in the body. Evidence regarding their chemical composition, properties, occurrence, and physiological rôle in both plants and animals is rapidly accumulating. Advances in this field of human knowledge should be even more rapid during the next decade.

At present there is satisfactory evidence of the existence of ten vitamins, and there is some good evidence that others also exist. In recent years the chemical structure of many of the vitamins has been determined. The daily requirement of any given vitamin is exceedingly small relative to that of the primary foodstuffs, but these minimal quantities may determine the difference between disease and normal health. Attempts to purify them have diminished the actual quantities which must be administered to animals or man to maintain normal body functions.

That disease in man may result from deprivation or deficiency of a food factor or other requirement of the body as well as from the invasion of agents from the outside, such as bacteria, parasites, poisons, etc., is now well recognized.

Partial vitamin deficiency is known as *hypovitaminosis,* and total deficiency as *avitaminosis.* The term *deficiency disease* is used without reference to severity. Symptoms arising from secondary infections, which gain a foothold in consequence of the lowered resistance of the body as a result of the deficiency, must not be confused with those specific to the disturbance.

Vitamin A or epithelial protecting vitamin

The primary result of omission of *vitamin A* from the diet is a structural change in the cells covering various surfaces both inside and outside of the body and of the cells which compose the various glands (epithelial cells). These surfaces include the skin, the mucous membranes of the air passages and digestive tract, the kidneys, the urinary and reproductive tracts, the conjunctiva (covering membrane of the eye and undersurface of the lids), the retina, the tear glands (lachrymal glands), etc. The disturbance is characterized by a *cornification* or *keratinization* (development of scaly or horny cells) with loss of vitality and sloughing. This vitamin is appar-

ently necessary for the normal functional state of these cells, but whether it is a necessary constituent of cell structure or only a stimulant *(catalyst)* to the cells is not known.

Vitamin A has been called the *growth vitamin,* also the *anti-infection vitamin* since animals deprived of it fail to grow and show marked loss of resistance to infectious diseases. With the possible exception of vitamin E, however, all vitamin deficiencies affect growth adversely and no single one should be designated as the growth vitamin. The increased susceptibility to infection associated with vitamin A deficiency is, most probably, secondary to the degenerative changes which occur in the protective membranes of the body which normally serve as barriers against the invasion of disease-producing organisms. Excess quantities of vitamin A neither offer an increased protection against infections nor alter the course or severity of infectious disease. Furthermore, conclusive evidence that vitamin A deficiency has any adverse influence on immunity (immunological reaction) to infectious diseases is entirely lacking.

Vitamin A deficiency may be due (1) to an absolute inadequate intake of this vitamin; (2) to deficient absorption and storage of it as a result of intestinal or liver derangement; or (3) to an increased need of the vitamin, as during rapid growth or disease. In the United States the food supply of the major portion of the population furnishes adequate amounts of this vitamin, principally in butter, milk, eggs, and green vegetables. A deficiency is less likely to occur in adults than in infants or young children, since the daily requirements of the vitamin are greater in growing individuals. Any excess of it in the food above the daily requirements is stored in the liver for future use. Before birth the young apparentlv obtain only minimal amounts of the vitamin from the mother since the livers of newborn animals contain very little of it.

Presumably the same is true for babies. However, after birth it is present in the liver in variable but appreciable amounts when foods containing the vitamin, or *pro-vitamin,* substances from which the vitamins can be manufactured, are fed, the amount stored depending upon the intake.

Vitamin A cannot be synthesized (manufactured from simpler substances) by the animal or human body. Man must therefore, depend upon his food for outside sources of it. It exists preformed in certain animal products such as cod-liver, shark-liver, and halibut-liver oils, butter, egg yolk, cream, and cheese; and to a lesser extent in the liver oils of other animals. Vitamin A precursors or pro-vitamins are synthesized by many plants with the aid of sunlight. These, when used for foods, supply animals with a source of it. Apricots, carrots, yellow corn, pumpkins, tomatoes, green vegetables, etc., are rich sources of the pro-vitamin but not of the vitamin itself. Some of these are characterized by the presence of a yellow pigment *carotene;* while in others this pigment, although present, is masked by the green chlorophyll. The importance of carotene to these plants is not understood, but it probably serves some important purpose. The vitamin A potency of foods runs parallel to their content of this pigment.

Vitamin A, however, is not identical with carotene since cod-liver oil, although rich in the vitamin, contains none of it. The evidence now available clearly demonstrates that carotene, chemically $C_{40}H_{56}$ (Smith), is absorbed unchanged from the intestine. It is then carried by the blood to the liver where it is chemically split, by enzymes, into two portions, one or both of which is vitamin A. It is an unsaturated alcohol $C_{20}H_{30}O$. Unlike carotene, it is colorless; it is not an oil, but it occurs dissolved in liver oil, etc., with the unsaponifiable fraction. Only a small fraction of 1 per cent of cod-liver oil is vitamin A.

Vitamin A is readily destroyed by oxygen or oxidizing agents at high temperatures, but is more or less protected from such destruction by other substances which occur with it in nature. Recent studies indicate that neither fruits nor vegetables lose appreciable amounts of this vitamin in the process of home cooking or canning.

Associated with the inadequate dietary of countries like China, India, Ceylon, and Africa; and also with the vicissitudes of war, famine, drought, and extreme poverty in any country, vitamin A deficiency disturbances have been commonly observed. Mild grades of the deficiency are characterized by dryness of the skin and eruptions which occur over most of the body except the face. The seat of the trouble seems to be in the sebaceous (oil) glands which open into the hair follicles. The most prominent sign of avitaminosis A is a peculiar soreness of the eyes which is characterized by dryness of the conjunctiva. This condition of dryness is due to a deficient secretion of the tear gland and is known as *xerophthalmia* (dry eye). It progresses rapidly and is associated with degenerative changes in this membrane, swollen lids, pus, and sticking or gumming of the eyelashes. The cornea, or front surface of the eyeball through which the light must pass to the retina, becomes opaque and vision is impaired.

Probably the most significant symptom of human vitamin A deficiency is that known as *night blindness*. It has been shown that the *visual purple*, a pigment of the rods of the retina, is elaborated from this vitamin. Vitamin A is brought by the blood to the retina where it is combined with a protein to form visual purple. Normally, under the influence of light, photochemical changes occur in this pigment and it is converted into *visual yellow*—when it is said to be bleached. This change leads to the stimulation of the visual image. The visual yellow is in turn broken up, yielding vitamin A, a protein, and waste products. Normally, visual purple is again formed from the utilizable end products, plus new supplies, and the process repeats itself. Visual purple is essential for the delicate vision necessary in dim light or night vision. Diminished vitamin A intake in the food naturally leads to a deficiency of visual purple and varying degrees of night blindness. Day vision is apparently not affected.

Other disturbances of avitaminosis A are respiratory infections such as catarrh of the respiratory passages and increased susceptibility to pneumonia, middle ear infections, kidney troubles, kidney stones, digestive disturbances, and sterility in both sexes.

Vitamin B_1 or anti-neuritic vitamin

Vitamin B_1 occurs in yeast, plant seeds, green vegetables, and fruits where it is synthesized. When these are fed to animals, the absorbed vitamin is stored in the cells of such organs as the liver, kidney, heart, and nervous system; and is present in such animal products as egg yolks and milk. Yeast is a very rich source of it. In grains it is present in the germ and beneath the covering layer, but is removed with the bran or polishings of such grains as wheat and rice during the milling and refining process. Such refined cereals become practically useless as sources of vitamin B_1 (thiamine). Milk is a relatively good source A small part of the thiamine in milk may be destroyed by pasteurization. It is, however, advisable, if not necessary, that the food of infants be supplemented with vitamin B_1 from other sources. The content of this vitamin in milk can be increased somewhat by feeding it to the mother or to the cow from which the milk is obtained.

Pigeons or young white rats are the usual laboratory test animals for vitamin B_1. Deprivation of this factor from the food of a young pigeon, as in feeding polished rice together with adequate amounts of each of the other food factors, almost immediately leads to refusal of food, cessation of growth, loss

of weight, muscular weakness, slow heart rate, sluggish gastro-intestinal activity, diminished secretion of digestive juices, digestive disturbances, and characteristic changes in the nerves and central nervous system (polyneuritis). These are associated with pain, paralysis, and finally death. Additions of small amounts of vitamin B_1 to the diet in the form of rice polishings or yeast almost miraculously restore the animal to health or if added to the original diet prevent the onset of these disturbances. Since the most striking symptom of the deficiency is a derangement of the nervous system, the B_1 factor is also called the *anti-neuritic vitamin.*

In humans, vitamin B_1 deficiency results in a condition known as beriberi, a disease of oriental peoples whose diet consists largely of polished rice or other diets inadequate in their vitamin B_1 content. The disease is still prevalent in many countries and is characterized by inflammatory changes of the nerves, a neuritis resembling the polyneuritis in vitamin B_1 deficient birds, with pain, muscular weakness, paralysis, gastro-intestinal disturbances, etc. Evidence is also accumulating which shows that even today many children in America and Europe receive inadequate vitamin B_1 and that addition of this factor to the diet in the form of wheat germ or yeast may result in appreciably better growth and health. This is particularly true for the underfed children of the economically less fortunate classes. The disease is also prevalent in institutions where the inmates are poorly fed.

Vitamin B_1 has been prepared in crystalline form by several investigators. These crystals are comparatively pure. Its chemical formula is probably $C_{12}H_{16}N_4SO_2$. The daily dose which is required to prevent the usual deficiency symptoms in rats is 0.001 mg. (mg. = 1 milligram or 0.001 gram; 1 oz. = 28,350 mgs.). Similarly, the dose for pigeons is 0.0025 mg. and for man about 0.3 mg. One ounce of the pure vitamin would be sufficient to protect a man for 80 years against vitamin B_1 deficiency. It is a basic substance which is soluble in water. When dry, it may be heated to 100°C. for 24 hours without altering its activity, but the presence of water greatly accelerates its destruction by heat. As it occurs in foods, however, it is not destroyed in appreciable amounts in the process of cooking.

The primary physiological action of this vitamin seems to be concerned with the utilization of carbohydrate foods in the body, or, as it is called, with carbohydrate metabolism. Normally, the carbohydrates are stored in the body as glycogen, animal starch, which is mobilized when needed for energy and split chemically into lactic acid by appropriate tissue enzymes. Accumulation of this acid in muscles leads to fatigue. Normally, the lactic acid is then oxidized or changed back into glycogen to be used over again. Vitamin B_1 appears to be related in some way, at present not well understood, with the enzyme systems involved in these chemical changes. An accumulation of lactic acid in the tissues and blood is associated with vitamin B_1 deficiency in animals and man. Such individuals fatigue easily and recover slowly. The ability of the tissues to use oxygen is depressed, but this can be restored by addition of vitamin B_1.

In terms of the facts just presented, the accumulation of lactic acid in the nervous system, heart, muscles, blood, and other organs is probably the direct cause of the functional disturbances in these structures. The loss of appetite, refusal of food, retarded growth, loss of body weight, the pain, paralysis, weakness, etc. are probably secondary effects resulting therefrom.

Vitamin B_2 or G

Vitamin B_2—now also known as flavin, riboflavin, and vitamin G—was formerly thought to be the vitamin which prevents pellagra. This view has since been shown to be erroneous.

A yellowish pigment with green fluorescence had been known to be present in

milk for a number of years, but little attention was paid to it, since it was thought to be of no great importance. This pigment was first called lactoflavin, later riboflavin. In 1932 it was found in yeast, and since then investigators have demonstrated its presence in a large number of plant and animal products.

In plants riboflavin is especially abundant in green leaves, less so in stalks and roots. This is a point of difference from vitamin A or provitamin A which, as in the case of carotene, may become more abundant in the root than in the leaf. Milk, liver, kidney, muscle and heart are good sources of riboflavin provided by animals.

Riboflavin and the respiration of the living cell

Riboflavin probably exists in every living cell, since it has been shown to be part of an enzyme or catalyst which chemically transports oxygen from outside the cell into it, where the oxygen is given up to the cell. Without riboflavin living cells appear to be unable to utilize oxygen.

The physiological significance of this vitamin seems to be related to oxidation in the tissues. The evidence indicates that it is necessary for the elaboration of an essential enzyme in the cells of animals, the *yellow oxidation enzyme*. The enzyme consists of a flavine, or vitamin B_2, in combination with protein. The enzyme has been crystallized. Both the flavine and the enzyme possess vitamin B_2 properties, but the free flavine alone has no enzyme activity. In foods of animal origin, 70 to 90 per cent of the vitamin B_2 activity is due to the enzyme, that is, to the combined form. The enzyme activity is destroyed by heat, whereas that of the vitamin is not. In alkaline solutions, however, the vitamin is destroyed even at room temperature.

Animals on diets deficient in riboflavin seem to be sicker than their general appearance would indicate. Before death they enter a stage of partial collapse, and death appears due to asphyxiation of the cells because of a lack of utilizable oxygen.

Riboflavin deficiency in humans

In 1938, a group of normal human beings was placed on a riboflavin-deficient diet. They developed lesions of the lips and contiguous skin, a condition known as cheilosis, which could be alleviated by the administration of riboflavin. This was the first evidence that riboflavin deficiency could cause a specific human disease. Since then naturally occurring cases have been recognized.

In 1939, it was shown that riboflavin may play a part in the causation of pellagra. This disease is usually relieved by the administration of nicotinic acid, another member of the vitamin B-complex, but some patients do not improve until both nicotinic acid and riboflavin are taken.

In 1940, it was shown that riboflavin deficiency may cause certain diseases in the eye, particularly a form of iritis and a disease of the cornea, termed interstitial keratitis. Patients with this type of lesion, complaining of sensitiveness to light, dimness of vision and eyestrain, were relieved in a short time after taking the vitamin.

Vitamin B_2 has been prepared in crystalline form and has been synthesized. It is more heat-stable than vitamin B_1, but is destroyed by exposure to light, particularly by the blue, violet and ultra-violet radiations.

The pellagra-preventive vitamin

Nicotinic acid, the P-P (pellagra-preventive) factor, is abundant in yeast, liver, milk, lean meat and legumes. This vitamin appears to be essential to the integrity of the body cells, and necessary for the normal functioning of the gastro-intestinal tract, the skin, the nervous system and probably other systems. In pellagra victims it cures mucous colitis, Vincent's infection, constipation and diarrhea. In dogs it cures blacktongue.

More than nicotinic acid may be needed to cure pellagra. In some cases, thiamine or riboflavin or both must be used in conjunction with nicotinic acid to complete the cure.

Vitamin C or the anti-scorbutic vitamin

Scurvy or *scorbutus* is a disease of man and of animals. It is characterized by destructive changes in the walls of blood capillaries which lead to hemorrhages beneath the skin, in the mucous membrane of the intestine, etc., in the joints and in the internal organs; by swollen, spongy, bleeding gums, and loose teeth; by the withdrawal of calcium from the bones, rendering them porous, spongy, and fragile; by swollen, extremely tender joints, and by dropsy and anemia in many cases. In young animals the enamel and cement of the teeth fail to develop.

The disease has been known from the earliest times and before the discovery that citrus fruits exert a protective action, it was prevalent among sailors on long voyages, soldiers, pioneer settlers, under conditions of famine and deprivations of war, and even among the inhabitants of the various civilized countries. It is still fairly common among the natives, children and adults alike, in South Africa and Central Australia. By employing the capillary-resistance test to determine the occurrence of low-grade scurvy in Scandinavia, Gothlin found that one out of every five apparently healthy school children between the ages of eleven and fourteen was suffering from vitamin C undernourishment. Such low-grade scurvy is higher in winter and spring than in the summer and autumn, corresponding to the lower vitamin C intake during the winter months, and may occur in any place where the food supply is deficient in this vitamin.

Vitamin C is present in oranges, lemons, grape-fruit, peppers, tomatoes, raw cabbage, paprika, and horseradish in rather large amounts. Potatoes, carrots, apples, and bananas contain less of it; but since they are eaten in relatively large amounts, the supply of this vitamin from these sources is very appreciable. Vitamin C is destroyed by heating, salting, drying, aging, and exposure to air and light. Pasteurization may destroy 20 to 40 per cent of that found in milk, which is already a poor source of it. Its destruction is chiefly through oxidation. In the canning and cooking process much of the vitamin may be conserved by eliminating oxygen, a condition which is approximately obtained in pressure cookers, and by keeping the contents acid. Condensed milk and milk powders contain appreciable amounts of it. Canned tomatoes retain most of their vitamin C content because of their acidity. Most grains do not contain this vitamin, but synthesize it during the process of germination.

Rats and dogs are able to synthesize vitamin C in their bodies, but guinea pigs, chickens, monkeys, and man cannot. For this reason the last group of animals must have an adequate supply of it in their food if scurvy is to be prevented. When the quantity ingested is in excess of the body needs, it is stored in the suprarenal gland, pituitary gland, intestinal wall, kidney, liver, ovary, eye, muscle, etc. These structures when used as food serve as valuable sources of it. The vitamin so stored during life is mobilized, and therefore diminishes in quantity, during severe exercise and other conditions of strain. The available supply is low or absent in scurvy, even in low-grade cases the store of vitamin may be exhausted during activity. Muscular weakness and fatigue are early symptoms of the deficiency.

The vitamin C content of the tissues of human beings has been found to vary widely among individuals, some having 3 times as much as the average, others only 1/10 as much, depending both upon the intake of the vitamin and upon the daily needs. Many of those having little of it were, no doubt, in a state of low-grade scurvy. The minimal daily requirement for complete prevention of the disease in an adult is 25 to 40 mg. of the vitamin or about 1/4 mg. per pound of body weight. Children seem to require about twice as much per unit body weight for protection as do adults.

Vitamin C has been identified, both chemically and by its physiological action, as a sugar acid which was first named *hexuronic acid* and having the formula $C_6H_8O_6$. Because of its antiscorbutic properties, it is now generally known as *ascorbic acid,* or *cevitamic acid.* It has been prepared in crystalline form, presumably pure, from peppers, lemons, oranges, cabbage, and suprarenal glands. It has also been synthesized in the laboratory and is now available commercially in crystalline form. Ascorbic acid has the same physiological action as vitamin C and has been used to cure scurvy in man.

One mg. of ascorbic acid contains 20 International Units (I.U.) of the vitamin, the new I.U. of 0.05 mg. of this acid now replaces the old one of 0.1. c.c. of lemon juice. Lemon juice contains about 0.5 mg. of the acid per c.c., similarly, orange juice contains 0.6 mg. and tangerine juice 0.37 mg. per c.c.

The physiological action of ascorbic acid, vitamin C, is apparently related to its unique reducing properties. It readily combines with oxygen, only to release it again when it is needed, thus it acts as an oxygen carrier or transporter. Similarly, it readily gives up two hydrogen atoms and reduces other compounds and in turn removes an equal amount of hydrogen from other substances to oxidize them. In this way it serves as an agent in the enzyme systems of oxidation and reduction associated with tissue respiration and metabolism. The low oxygen consumption of scurvy animals, also of their isolated tissues, may be increased to normal by treatment with ascorbic acid.

The presence of ascorbic acid in the suprarenal gland protects the destruction of adrenine its specific secretion, by oxidation. Similar protective functions may be present in other tissues. Some of the vitamin is excreted by the kidneys.

Vitamin D or anti-rachitic vitamin

Rickets occurs in both man and animals as a result of (1) improper intake of calcium (Ca) and phosphorus (P), (2) an inadequate supply of vitamin D in the diet, (3) insufficient solar radiations, or (4) a combination of these. The disease is characterized by a deficient calcium phosphate deposition in the growing portions of young bones, resulting in abnormal cartilage growth, softer bones, and consequently deformities in their shape and structure. Improper development and calcification of the teeth are also usually present and probably associated with a predisposition to dental decay and caries. In adults the condition is characterized by the withdrawal of calcium phosphate from the bones, which makes them more porous *(osteoporosis)*. This bone disease is known as *osteomalacia.*

Neither children nor adults need have rickets. However, the disease, although in a less severe form, is still quite prevalent in certain places. Juvenile and adult rickets are rampant in China and India, where Wilson showed that both the lack of vitamin D and exposure to solar radiations are contributory causes. Among school children between the ages of 5 and 17, in congested cities 58 per cent gave evidence of active rickets; in smaller cities and well planned suburbs the values were 32.5 and 17.6 per cent respectively. In 1928 the majority of children in London elementary schools gave evidence of having had rickets. In all probability such surveys in other localities would reveal similar conditions. Hess states that no less than 75 per cent of breast-fed babies show signs of rickets.

That experimental rickets can be produced by deprivation of, and later cured by addition of a fat-soluble vitamin to the diet of animals was demonstrated by Mellanby in 1918. The usual test animals for studying it are rats, mice, and chickens. In 1922 McCollum and his associates identified vitamin D as being distinct from fat-soluble vitamin A. A rachitic rat will respond to less than one part of vitamin D per billion in the diet. Nearly all fish-liver oils

contain it. The following table contains a few of the more important ones and expresses the vitamin D potency of each in International Units per gram.

Liver oil source	I.U. per g.
Bluefin tuna	40,000
Swordfish	10,000
Chinook salmon	1,300
Halibut	1,200
Boston mackerel	750
Turbot	260
Cod	100
Yellow sole	90
Shark	50
Haddock	10
Sturgeon	nil

It is also present in appreciable amounts in egg yolk and in the skins of animals and humans who are exposed naturally to the irraditions of the sun *(ultraviolet)* or to artificial sources of ultraviolet. Foods such as milk, butter, green vegetables, and vegetable oils are normally negligible sources of it; but the vitamin D content of milk and eggs can be increased by feeding the animal a diet rich in it.

Deficiency of vitamin D is considerably more likely to occur than deficiency of any other vitamin, especially during the winter months or in geographical areas where the sky is clouded a large portion of the time. For this reason care should be exercised in supplying it in the diet or by means of artificial radiations.

That rickets can be cured by ultraviolet irradiations was first definitely demonstrated by Huldschinsky in 1919. Hess, Pappenheimer, and Weinstock in 1922 showed that the wave lengths of light possessing these properties were the shorter ultraviolet waves of the solar spectrum and the still shorter waves of artificial ultraviolet. In 1924 it was shown by Hess and by Steenbock and their associates that irradiations of various food substances with ultraviolet endowed them with antirachitic properties which they did not possess before. This indicates that these foods contain a substance—*pro-vitamin*—which can be changed into the active vitamin by ultraviolet. The pro-vitamin was identified as *ergosterol* by Windaus and Hess and by Rosenheim and Webster almost simultaneously in 1927.

Chemically, ergosterol is $C_{28}H_{43}OH$ It is a white, crystalline, heat-stable powder. It is poorly absorbed from the intestine and does not possess antirachitic properties. Its almost universal occurrence is indicated by the wide variety of edible foodstuffs which acquire the antirachitic properties of vitamin D when irradiated. The distribution of vitamin D or activated ergosterol is considerably more restricted both in extent and amount. The activated vitamin probably does not occur in living plants.

Ultraviolet irradiation of ergosterol alters the internal structure of its molecule without affecting its elementary composition. Associated with this change, however, it develops very striking antirachitic properties equivalent to about 25,000 I.U. per mg. Unlike ergosterol, it is absorbed with ease. Viosterol is a commercial form of irradiated ergosterol. From irradiated ergosterol a number of substances have been separated which possess different physiological properties. One of these is an extremely potent antirachitic factor which has been named *calciferol* ($C_{28}H_{43}OH$); other fractions are inactive, and still others are poisonous. Apparently calciferol is the vitamin in its pure state. The antirachitic potency of pure calciferol is given as 40,000 I.U. per mg., an activity 400,000 times that of cod-liver oil.

The consensus of opinion of leading investigators is that the smallest dose of vitamin D which can be relied upon to prevent rickets or to heal mild rickets in infants is about 3,000 I.U. of irradiated ergosterol or 1,000 I.U. of cod-liver oil per day for several weeks.

The evidence seems to be rather conclusive at present that there are several forms of vitamin D, that is, there are sterols (pro-vitamins) other than ergo-

sterol which can be activated by ultraviolet irradiations. The fact that irradiated ergosterol and cod-liver oil, rat unit for rat unit, are not equally potent when administered to children or chickens, supports this conclusion.

Vitamin D is the only vitamin which is quite certainly synthesized in the animal body; but the relative inadequacy of this synthesis, under our conditions of living, is indicated by the readiness with which children and even animals develop rickets. Except for the occasional amounts of the vitamin obtained by eating such foods as fish, liver oils, and eggs, it must normally be obtained from exposure of the body to the sun's rays or to other sources of ultraviolet. The skin contains some ergosterol which when activated by radiation may be absorbed into the blood to aid in supplying the needs of the body for it. This has been the usual explanation for the beneficial effects of irradiation of the skin in the prevention or cure of rickets, but Hou has recently shown (1930) that the secretions of the sebaceous glands of the skins of man and animals, and of the preen glands of birds, contain ergosterol which becomes vitamin D upon irradiation. Normally this is readily absorbed through the skin; or, in the case of animals, it is obtained by licking the hair, feathers, or skin; or it may be eaten with these as food. If the skin, hair, etc. are kept perfectly cleansed and free from fat, the effectiveness of ultraviolet in curing rickets is almost lost. It is well known that if horses and other herbivora are kept scrubbed thoroughly with soap and water or if other animals are prevented from licking their fur or feathers, they do not thrive.

Normally, growth and metabolism of bones not only require proper concentration of Ca and P in the blood, but also that they be present there in the proper form and ratio to one another. In rickets either blood P or Ca or both may be subnormal, and improper deposits of calcium phosphate or even withdrawal of bone salts occur. According to Harris (1932), vitamin D exerts its action in raising the blood Ca and P principally by increasing their net-absorption from the intestine. Normally, these are absorbed in the upper intestine and excreted, in part, in the lower portion of the bowel. The vitamin then may act either by increasing their absorption or by decreasing their excretion. Evidence at present favors the latter interpretation. The vitamin facilitates the maintenance of normal blood Ca and P levels; these in turn lead to proper bone formation.

Excessive doses of vitamin D in the form of viosterol or calciferol are known to produce high blood Ca and P and abnormal deposits of calcium phosphate and calcium carbonate in tissue other than bone. Such calcifications have been observed in the blood vessels, heart, kidneys, stomach, muscle, etc. The salts usually come from the diet, but if this is deficient or the vitamin dose is enormous, they may be withdrawn from the skeleton. Although a slight excess of the vitamin may lead to better bone formation, extreme excesses usually lead to bone resorption as the salts are being deposited in abnormal places.

The doses required to produce these effects are, however, very large. Rats may withstand 10,000 times the rickets-prevention dose before signs of abnormal calcification occur. The margin is not so wide for man, but is still large. According to Crimm and Reed, the danger point begins with a dose of approximately 600,000 I.U. daily over several weeks, or 200 times the ordinary preventive dose. The lethal dose is not known, but doses 6,000 times the ordinary amount have been given without fatal results.

The parathyroid hormone is also related to Ca metabolism. Vitamin D was once believed to exert its action through this gland, but this view has quite generally been discarded. The parathyroid hormone has no effect on the net-absorption of Ca and P from the intestine, and vitamin D still exerts

its normal action in the body after the parathyroid glands have been removed. Its action in raising blood calcium is accomplished by withdrawing the calcium from the skeleton.

Vitamin E or anti-sterility vitamin

When rats are fed adequate diets consisting of carbohydrates, proteins, fats, and each of the vitamins so far discussed, they frequently become sterile and are unable to reproduce. In females the ovaries and reproductive cycles appear to be normal. Ovulation occurs, but if the ovum is fertilized the embryo dies and is either absorbed or aborted within a few days. In males the germ cells and seminiferous tubules degenerate. These changes once developed are apparently incurable. They can be prevented if a small amount of wheat germ or embryo, lettuce, meat, liver, egg yolk, etc. is added to the diet. The factor is widely, though sparingly, distributed in other foods such as milk, cod-liver oil, and vegetable oils.

It has been obtained in crystalline form by Evans (1935) from wheat germ oil; chemically it is a complex higher alcohol. Vitamin E (fat soluble) has been synthesized and identified as alphatocopherol. The minimal rat dose of wheat germ oil is 0.1 mg. per day. The vitamin can be stored in the body. It is resistant to heat, light, and chemical reagents. Since the requirement of this factor in the animal organism is so small, the probability of its being involved in human sterility seems rather remote. However, beneficial effects have recently been reported for human cases of sterility and habitual abortion. Sterility in cattle has also been cured by it.

Vitamin K

The existence of a vitamin which plays an important part in the clotting of blood was first suspected by Dam, a Danish investigator, who found that if newly hatched chicks were placed on a fat-free diet they developed hemorrhages in the skin, the mucous membranes and other portions of their bodies. Dam found that a fat-soluble vitamin obtained from green vegetables could prevent this tendency to bleeding. He termed this substance vitamin K, for the first letter of the Danish word for coagulation. Doisy, an American investigator, succeeded in isolating two anti-hemorrhagic vitamins, K_1 and K_2.

It has since been found present in alfalfa, spinach, kale, carrot tops, soy bean oil, tomatoes, chestnut leaves, oat sprouts, putrefied fish meal, rice bran and casein. It has been discovered that it is manufactured by certain bacteria which are normally present in the intestinal tract.

One of the substances which causes blood clotting and which is normally present in the blood is known as prothrombin. This is reduced in vitamin K deficiency. It has not as yet been definitely determined whether the vitamin is an integral part of prothrombin or whether it merely stimulates the tissues of the body to produce prothrombin.

Though human beings and other animals absorb the vitamin from the intestines, there are certain conditions which interfere with absorption. Bile must be present in the intestines, and its absence in diseases such as obstructive jaundice and biliary fistula results in deficiency of the vitamin after a few weeks. This explains the tendency to hemorrhages in persons with jaundice.

Abnormal bleeding also occurs in several other diseases. These include hemophilia, or hereditary bleeding; scurvy; and thrombocytopenic purpura, a form of hemorrhage due to an insufficiency of the blood platelets. Vitamin K is of no use in these conditions.

Other vitamins

Two other vitamins—pantothenic acid and vitamin B_6 (pyridoxin)—are known. Both are members of the B group. Though the chemical structure of the two vitamins is known, they are still being investigated to determine the part played by them in human nutrition.

SHADOWS IN THE HEAVENS

The Conditions of Eclipses of the Sun and Moon, and the Strategy of Observation

DOES GRAVITATION BEND LIGHT RAYS?

AN eclipse of the moon, and still more an eclipse of the sun, must always be a strange and awe-inspiring spectacle. The word "eclipse", meaning in Greek "fainting" or "failing", shows what the ancients felt as they watched the darkening of the heavenly lights; they saw them languish and swoon under some dreadfully ominous visitation. Eclipses, like comets, were taken to be portents of war, pestilence, the death of princes, or even of the end of the world; and to this day certain more primitive peoples come to the aid of the sun or moon with various rites and clamorous supplications.

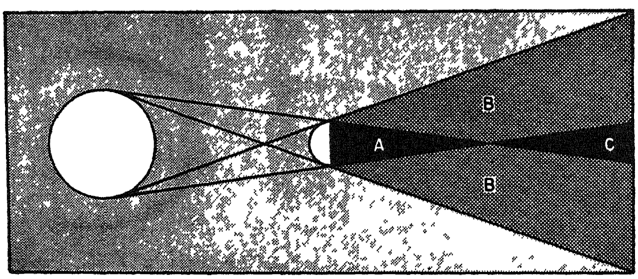
Eclipses are caused by the shadows of the earth and of the moon. The earth and moon being opaque bodies, each of them always has a shadow extending outward into space away from the sun; and because both earth and moon are smaller than the sun, the shadow of each of them is conical, and diminishes in diameter as it proceeds outward into space, until it comes to a point. As the moon travels round the earth once in every month, it sometimes throws its shadow on a portion of the earth's surface, and sometimes its own globe enters into the earth's shadow. The former case, causing a solar eclipse, can only take place at new moon; the latter, causing a lunar eclipse, can only take place at full moon. There would, therefore, be an eclipse of the sun at every new moon, and an eclipse of the moon at every full moon, if the moon's orbit round the earth were quite in the same plane as the earth's orbit round the sun.

The moon's orbit, however, is not in the same plane as the earth's orbit, but is slightly inclined to it. The moon passes through the plane of the earth's orbit twice every month, being for half the month below that plane, and for half the month above it. Usually, therefore, the moon's shadow at new moon passes above or below the globe of the earth, and thus the moon fails to eclipse the sun. Usually, also, at full moon, the moon passes above or below the earth's shadow, and so fails to be itself eclipsed. But from time to time the moon is at full moon or at new moon at the moment when it is at one of the points where its orbit crosses the plane of the earth's orbit; and when that happens, there is a lunar eclipse at full moon or a solar eclipse at new moon. The plane of the earth's orbit round the sun, or, more precisely, the great circle in which this plane cuts the celestial sphere, is called the "ecliptic", and the points in the orbit of the moon where it crosses the plane of the ecliptic are called the "nodes" of the moon's orbit. Eclipses, whether of the sun or of the moon, take place when the moon is at or near the nodes of its orbit.

Let us now consider the different parts of the shadow which is thrown by the earth or the moon. They may be illustrated by a diagram which represents an opaque and non-luminous globe, illuminated by a larger and luminous globe. The diagram found on the next page does not represent the relative sizes or distances of the sun and earth, or of the sun and

moon, but it shows well enough the various regions of complete and partial shadow which are actually projected into space by the earth and the moon. In the first place, there is the central region of complete shadow, the umbra, marked *A*. No light comes directly from the luminous body to any object within the cone, but from the sun-lighted sky; and an observer within this cone cannot, therefore, see the source of light at all.

Secondly, surrounding the cone of complete shadow, there is a region of partial shadow, marked *B*. This is known as the penumbra. Any object within it receives light from a portion of the luminous body; and an observer within it can see a portion of the source of light. Thirdly, the lines, or rather the surface, bounding the conical region of complete shadow, if extended outward beyond the point of the cone, form an inverted cone, marked *C*, which is called the negative shadow. Any object within the negative shadow receives light from an external ring of the luminous globe; and an observer in any part of the negative shadow will see the source of light as a luminous ring round the opaque body which is interposed.



The degrees of darkness in eclipses, as explained in the text.

It is not difficult to calculate the length of the shadows of the earth and of the moon. It is evident from the diagram that the length of the cone of complete shadow depends upon three factors — the diameter of the source of light, the diameter of the opaque body, and the distance between these two bodies. These three factors are known with considerable accuracy, both in the case of the earth and in that of the moon. But while the diameters of the sun, earth and moon are constant factors, the distance between sun and earth and between sun and moon are variable factors. Consequently, the shadow of the earth and the shadow of the moon vary in length. The length of the earth's shadow, at its longest, is about 871,000 miles; at its shortest, about 843,000 miles; and at its mean, about 857,000 miles. The length of the moon's shadow is about 236,000 miles at longest, about 228,000 miles at shortest, and its mean is about 232,000 miles.

The length of the earth's shadow being about 857,000 miles, and the average distance of the moon from the earth being only about 239,000 miles, it is obvious that when the moon plunges into the shadow of the earth it is much nearer to the base than to the tip of the conical shadow. The diameter of the cone, where the moon passes through it, varies from about twice the diameter of the moon to about three times that diameter. If the path of the moon happens to go right through the center of the shadow, the moon may remain totally eclipsed for about two hours. To this time must be added another hour from the first contact of the moon's disc with the shadow until the moment of total eclipse, and yet another hour during the emergence of the moon from the shadow, so that a lunar eclipse may last, from beginning to end, as long as four hours.

On the other hand, the total phase of the moon's eclipse may last only a few minutes if the path of the moon takes it near the edge of the shadow. If the moon's path is such that only a portion of its disc, and not the whole, enters into the conical shadow, the eclipse is partial and not total. Sometimes its path, escaping the cone of complete shadow, takes the moon through the penumbra of the earth, but under these circumstances so much light is still received from a portion of the sun's disc that there is no marked obscuration of the moon unless it passes very close to the true shadow.

The moon is usually not altogether lost to sight even in the midst of a total eclipse, but shines with a strange, lurid, copper-colored glow. Although the earth's globe, so much larger than the moon, is interposed directly between it and the sun, yet sunlight reaches the moon's surface with sufficient illumination to show up the main lunar features. Sunlight is bent around as it passes through the earth's atmosphere. When we witness from the earth a total eclipse of the moon, observers on the moon would see a total eclipse of the sun, but they would see the great ball of the earth surrounded all round its edge by a glowing ring of sunlit atmosphere; and the rays which would thus reach their eyes constitute the light that illumines the moon during total eclipse. The terrestrial atmosphere acts as a lens, bending some of the sunlight which passes through it into the shadow of the earth. If, however, the earth's atmosphere be heavily laden with clouds, and is consequently comparatively opaque, it fails to deflect sunlight into the earth's shadow; and under those conditions the moon's surface may be so obscured as to be altogether invisible. The lurid ruddy color during an eclipse is due to the quality of the atmosphere to which we owe the gorgeous tints of sunset. The light which thus passes from the sun to the eclipsed moon has obviously had to traverse more than twice the distance through the atmosphere which the rays of the setting sun have to traverse before they reach our eyes; and the tinting effect of the atmosphere, with which we are familiar in sunsets, is more than doubled.

Eclipses of the moon are not quite so frequent as eclipses of the sun. There are years within which there is no eclipse of the moon; and in general it may be said that there cannot be more than two lunar eclipses in any one year. If, however, there is an eclipse of the moon on one of the first days of the year, it is possible that there may be a third eclipse in December. The statement that eclipses of the sun are somewhat more frequent than eclipses of the moon seems to be contrary to our experience, for everyone must have noticed that in the country where he lives eclipses of the moon are considerably more frequent than eclipses of the sun. These two facts are not really in contradiction with each other. The moon's shadow in a solar eclipse covers a small space on the earth, whereas the earth's shadow in a lunar eclipse, covers more than twice the moon's diameter. Every eclipse of the moon is therefore visible to the inhabitants of more than one-half the earth's surface, but the regions from which any particular eclipse of the sun can be seen lie in a very narrow track across the globe.

A SOLAR ECLIPSE VIEWED FROM SPACE

Astronomers have to undertake expeditions to remote corners of the world to study eclipses of the sun, but eclipses of the moon can be seen at home. Yet, from the astronomical point of view, eclipses of the sun are incomparably more important, as well as more frequent. There are at least two solar eclipses every year, and there may be as many as five.

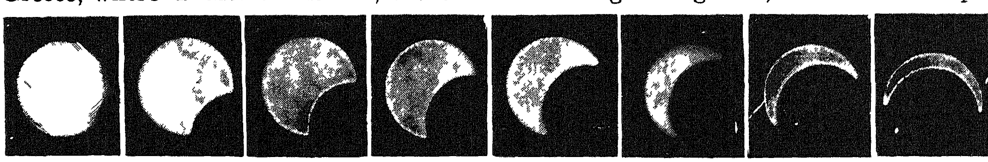
Inasmuch as eclipses both of the sun and of the moon depend upon the regular movements of these bodies, their occurrence, both in the future and in the past, can be calculated with great exactness. Thus we know from published tables, of which the best known are Oppolzer's, that within the decade starting in 1940, total

eclipses, excluding annular total eclipses, will take place on the following dates: October 1, 1940; September 21, 1941; February 4, 1943; January 25, 1944; July 9, 1945; May 20, 1947; and November 1, 1948. Of these eclipses one will be visible in part of the United States, that, namely, occurring in 1945. The list of future eclipses might be indefinitely extended for thousands of years to come.

The power, within certain limits, to foretell the occurrence of an eclipse appeared very early in the history of scientific knowledge. The Chaldæans were able and patient students of the heavens: we have, for instance, records of a total eclipse of the sun observed in Babylon as early as 1069 B.C.; and many centuries before our era every considerable city in the region of the Euphrates and Tigris had its observatory and official astronomers. Thence astronomical knowledge passed to Greece, where Thales of Miletus, the earliest of Greek philosophers, made a vast reputation by predicting an eclipse, which duly took place, on May 28, 585 B.C.

This early astronomical feat is, after all, not so surprising as it may appear, for patient observers who were careful to keep records of celestial events must soon have become aware of the periodic recurrence of eclipses of the sun and of the moon. Such is the regularity of the movements of the heavenly bodies that whatever eclipses take place in any particular year will be repeated after an interval of eighteen years eleven days and about eight hours, so that eclipses come round again at the right time with the precision of the hands of a clock. This period of recurrence is still known as the "saros", a name meaning "repetition", applied to it by the ancient Chaldæans. In each saros there are about seventy eclipses, including about forty eclipses of the sun and about thirty of the moon.

It must be added, however, that although each eclipse of the sun or moon recurs after this period of eighteen years and eleven and one-third days, every such eclipse only has a certain limited life, the life of a solar eclipse being considerably longer than that of a lunar eclipse. Thus, an eclipse of the sun begins as a partial eclipse, in which the moon only slightly encroaches on the sun's disc. At the recurrence of the same event after the period of the saros, the moon obscures a larger area of the sun. Next time, the eclipse, though still partial, is again greater in extent; and this extension of the eclipse is repeated after every saros. These partial eclipses are followed ultimately by a series of annular and total eclipses, in which, from some place on the earth's surface, the moon is seen to pass across the center of the sun's disc, either nearly covering it, as in an annular eclipse, or obscuring it altogether, as in a total eclipse.



10 55 a m 11 5 a m 11.15 a m. 11 25 a m 11 35 a m 11 45 a m. 11 55 a m 12 5 p m.

PARTIAL ECLIPSE OF THE SUN —

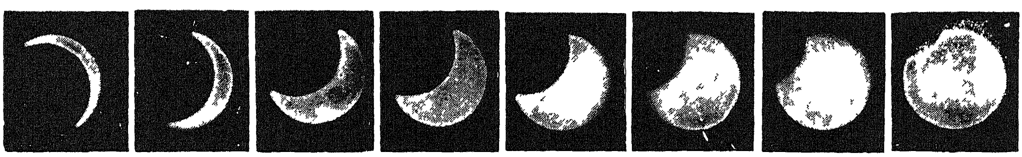
Finally, the eclipse dies out, as it arose, by a series of ever-diminishing partial eclipses In this way the same solar eclipse returns at the interval of the saros, at least sixty-eight times and it may be as often as seventy-five times, the whole process, from its first to its last appearance, covering nearly thirteen centuries. Any given eclipse of the moon increases and declines in the same way, but has a shorter life, recurring only forty-eight or forty-nine times, at intervals of eighteen years and one-third days; so that the whole life of a lunar eclipse, from its first to its last appearance, extends to less than nine centuries.

Eclipses of the sun are of three kinds — partial, annular and total. An observer situated within the penumbra of the moon, marked *B* on the diagram on page 2584, sees a partial eclipse; one within the negative shadow, *C*, an annular eclipse; and one within the true shadow, *A*. a total eclipse.

We have seen that the mean length of the moon's shadow is about 232,000 miles, and its greatest length is about 236,000 miles The mean distance of the earth from the moon is, however, a little over 238,800 miles, so that in general the moon's conical shadow is not long enough to reach the earth. At times, however, the moon is within less than 218,000 miles of the earth's surface, and the true shadow may then completely hide from the sun's rays a small area of the earth's surface, causing at that point a total eclipse of the sun over an area which cannot exceed 167 miles in diameter. At other times the moon may be nearly 249,000 miles away from the earth's surface; and if it is then interposed between the sun and the earth its negative shadow will partially obscure a small area of the earth's surface, causing at that point an annular eclipse of the sun. Around the area on the earth's surface where there is total eclipse or annular eclipse of the sun, there is always a very much larger area where there is partial eclipse. This area of partial eclipse, caused by the penumbra of the moon, always extends for about two thousand miles over the earth's surface on each side of the path which is followed by the area of total eclipse: sometimes the area of partial eclipse extends as far as three thousand miles from the path of totality.

The path over the earth's surface, which the area of total eclipse will traverse at any given eclipse of the sun, is carefully computed and mapped beforehand, so that astronomers may take up advantageous positions for observing the eclipse. The moon's shadow passes along this track at a great speed, considerably exceeding a thousand miles an hour; and the longest period for which totality can last at any one point, under the most favorable conditions, is just short of eight minutes.

The approach of a total eclipse of the sun is always described as impressive and even alarming. The clouds darken, the air becomes chill, and a murky gloom pervades the sky. Birds fly to shelter, and other animals show signs of alarm The temperature falls and darkness rapidly increases. Then the black shadow of the moon, like that of a vast thundercloud, advances with fearful rapidity from the western horizon, covers the land and enfolds the observer. Usually, just before the last rays of the sun are obscured, swiftly moving bands of light and shade, probably due to uneven refraction in the atmosphere, pursue one another over any extended white object. Then the day is like night: but as the eyes become accustomed to the darkness, surrounding objects are seen in strange appearance, without their natural colors. The beholder has the sense of impending calamity. All nature appears to be dead.



12 11 p m — 12 21 p m — 12 31 p.m. — 12 41 p m — 12 51 p m — 1 1 p m — 1 11 p m — 1.21 p.m

A SERIES OF PHOTOGRAPHS

In the sky, as the eclipse approaches totality, the sun is seen as an excessively narrow crescent of brilliant light, round the eastern edge of the advancing moon. This crescent becomes a mere curved line, and then breaks up into irregular beads of light, known as Bailey's beads. These beads of light are caused by the sun's light shining through uneven places on the edge of the moon—or through what we might call lunar valleys.

The chromosphere with its prominences, and the corona, which have been already described in Chapter 22, are among the chief objects of study during a total eclipse. But a modern eclipse expedition investigates these structures in several ways, and undertakes many other observations also, and is altogether a very elaborate undertaking, employing many hands and equipped with very elaborate and costly apparatus. Parties of this kind go out from each of the countries which are more

advanced in scientific interests, and often two or three parties from one country; and in the case of the more accessible eclipses these more or less official expeditions are followed by many amateur astronomers. The track of the moon's shadow is dotted in advance with temporary observatories, occupied by eagerly expectant students.

One of the most important points to be determined during a total eclipse of the sun is the precise moment of each of the four contacts. These contacts are. first, when the moon first encroaches on the sun's disc; second, when the last rays of the white light of the photosphere are cut off, and the moon stands out like a round black ball against the corona; third, when the first gleam of the white light of the sun reappears; and fourth, when the moon passes completely off the sun's disc. These times of contact are observed both by the eye with the aid of a telescope, and by means of photography.

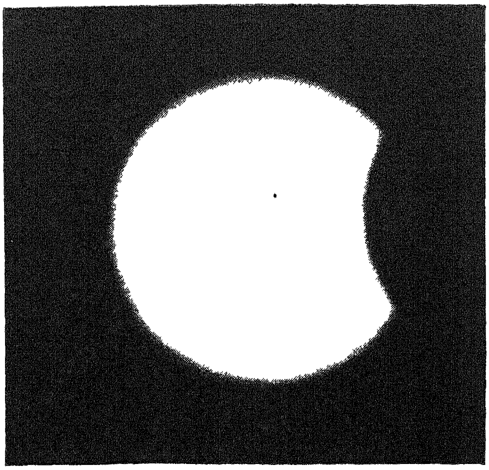
The chromosphere and prominences can now be studied, as we have seen, by means of the spectroscope at all times, so that they no longer take up quite so much attention during the brief and valuable moments of eclipse. Observations of the corona, which astronomers formerly could see only during total eclipses of the sun, can now be made with the recently invented coronagraph at any time. The observer who is observing visually is blindfolded for ten minutes before the moment of total eclipse, so that his eyes may be in the best condition to perceive the delicate, far-reaching streamers and filaments of light. For the same purpose opaque discs are erected on poles to cut off the brilliant light of the inner corona, so that observers in fixed positions behind them may be sensitive to its tenuous outer structures. Photographs of various lengths of exposure are taken of the corona, and its spectrum is recorded by means of the prismatic camera, in which separate images of the corona are formed, corresponding to each of its constituent elements.

The period of total eclipse is also utilized in searching for possible planets near the sun and within the orbit of Mercury. This search, formerly made by ocular observations with the telescope, is now made more rapidly and completely by means of photography, and the power and efficiency of these methods, thus far applied without results, make the existence of any such planet extremely improbable

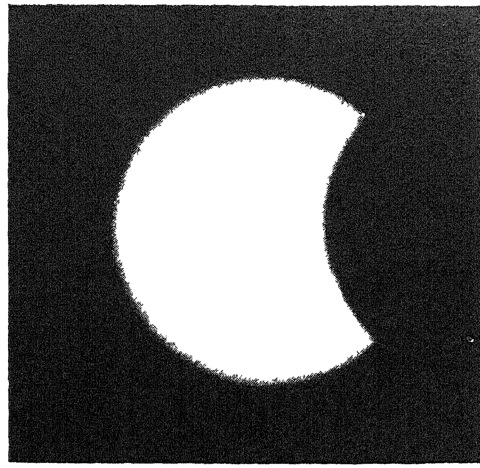
The bolometer, an instrument of exquisite delicacy in the measurement of heat radiation, is used to determine the heating effect of the radiation of the corona. The corona remains very much of a mystery to the astronomer, and the various theories which have been proposed concerning its nature have not thrown much light upon the subject. It may be caused by electrons from the sun. In the bolometer the heat-rays are spread out, as in the spectroscope, to form what is known as an energy spectrum, and the energy spectrum of the corona is compared with that of the sun itself. If the coronal light is reflected light, the energy spectrum of the corona will be similar to that of the sun, but if it is due to the incandescence of dust particles, the coronal energy spectrum should differ from that of the sun. Bolometric observations of the corona have led to the conclusion that its light is due principally neither to reflection nor to the incandescence of dust particles. The corona radiates too little heat to be quite consistent with either of those theories.

The development of the theory of relativity (explained at length in an earlier chapter) by Dr. Albert Einstein and others has added a new interest to solar eclipses and has presented a new problem of great importance to astronomers for solution. This theory is extremely abstruse and is still the subject of discussion in the scientific world. To bring it into contact with reality it was necessary to deduce from it conclusions that could be tested experimentally. Such a method had been pursued with signal success in regard to the theory of gravitation and the wave theory of light, and the verification of such conclusions deduced from Einstein's theory would be the best evidence of its probability, though it does not rise to the dignity of a demonstrative proof of its truth: for such a proof, it

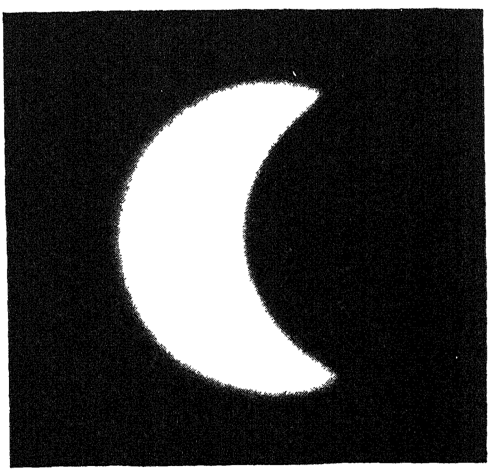
THE 1932 ECLIPSE AS SEEN IN NEW YORK, AUG. 31



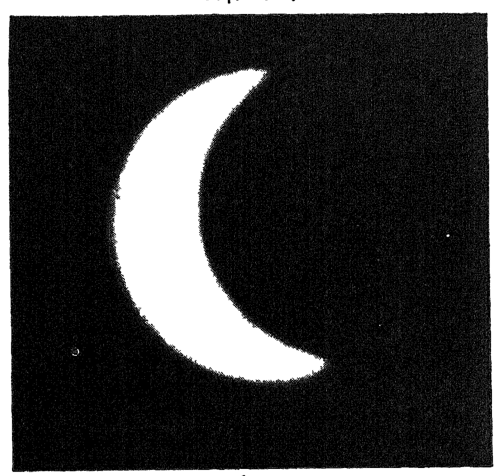
2 36 P. M.



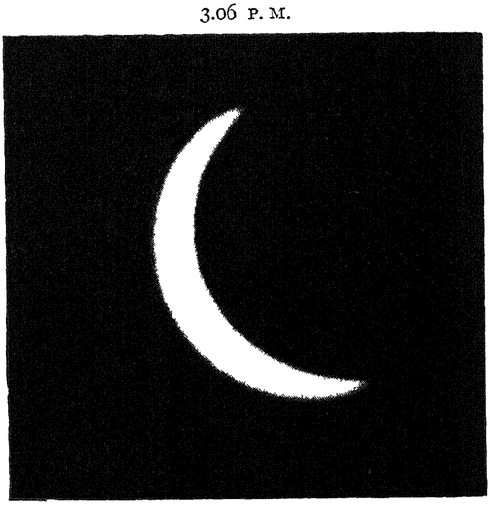
2.46 P. M.



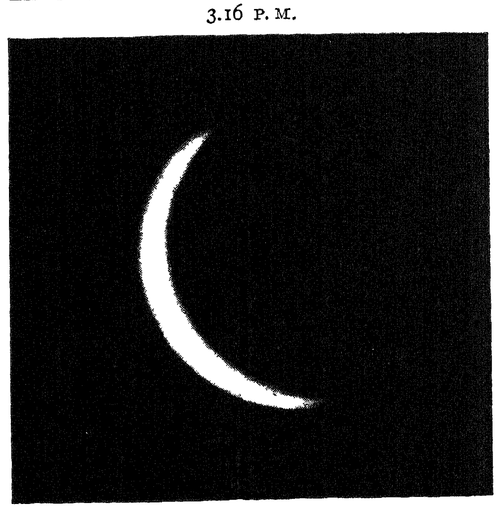
3.06 P. M.



3.16 P. M.



3.26 P. M.



3.34 P. M.

THESE HOURS ARE STANDARD TIME.

Courtesy, N. Y. Sun

would be necessary to show not only that the facts agree with the given theory but that there is *no other* probable theory sufficient to explain the observed facts. Dr. Einstein himself deduced three physical conclusions which might serve the purpose of testing his theory in the manner indicated above. The first of these has reference to the motion of the perihelion of Mercury. This motion has long been one of the outstanding problems of gravitational astronomy, since observation shows that it is more rapid than can be accounted for by all the *known* gravitational forces exerted on Mercury by the other members of the solar system ; the excess of the observed motion over the calculated motion, as deduced by different scientists, is from 29″ to 42″ per century. Now according to the theory of relativity the sun should produce an acceleration of 43″ per century over and above that required by the Newtonian mechanics; this agrees very closely with the larger of the values indicated above and was accepted as a confirmation by those inclined to favor Einstein's theory.

A second conclusion is that atoms should vibrate more slowly in a gravitational field and hence the spectrum of an element should be shifted to the red as compared with the spectrum of the same element outside the field. This has been verified in the stellar spectra.

Another conclusion deduced by Einstein is that a ray of light should be deflected in passing through a strong gravitational field. It would be impossible to detect such a deflection on the surface of the earth, but the sun's attraction being much greater than that of the earth would have a greater effect, and in 1911 Einstein calculated that a ray of light from a star passing close to the sun's limb should be deflected from its original course by $\frac{7}{8}$ of a second of arc; later on, as a result of further considerations, he announced that the deflection would be double this amount, or 1″.75. Such a phenomenon cannot be detected under ordinary conditions since no stars are visible in the intense glare of the sun in broad daylight. However, during a solar eclipse when the moon blots out the sun's light, stars appear in the darkened heavens in the neighborhood of the sun. The apparent success of the theory of relativity in the case of Mercury's motion suggested to astronomers the desirability of testing Einstein's second deduction at the first favorable opportunity afforded by a total eclipse. An extensive expedition was sent from the Lick Observatory to a station near Kiev, Russia, with special photographic lenses for this purpose on the occasion of the total eclipse of August 21, 1914, but thick clouds intervened and rendered the attempt unsuccessful; the same observatory made a second attempt at Goldendale, Washington, during the eclipse of June 8, 1918, this time with partial success. In 1919 another excellent opportunity offered itself for making these observations during the eclipse of May 29 of that year, and the Royal Astronomical Society sent out two expeditions for this special purpose, one to Sobral in Brazil, under Crommelin and Davidson, and the other to the Island of Principe, in the Gulf of Guinea, under Eddington and Cottingham. At the time of totality the stars in the region of the sun were photographed: the plates were then compared with photographs of the same region taken at night when the sun was in a different portion of the heavens. Careful measurements showed a distinct displacement of the star images in the eclipse photographs. Campbell's results, derived from the Lick plates of 1918, indicated a deflection at the sun's limb of 0″.58. Of the two sets of plates taken with different instruments by the British expedition at Sobral, one indicated a deflection of 1″.98, while the other set gave a value of about 0″.99.

The plates taken at Principe where conditions were less favorable gave a deflection of 1″.61. These values indicate a distinct and hitherto undetected deflection of a ray of light in passing near the sun's limb and hence constitute a discovery of fundamental importance. The numerical results, however, do not agree, either in magnitude or direction, as well as could be desired with Einstein's predicted value.

Campbell's value of 0″.58 is quite small and nearer the amount at first predicted by Einstein and also agreeing with that which would be due to the Newton-Maxwell effect, namely, 0″.87. It should be stated that conditions at the 1918 eclipse were not as favorable as those prevailing during that in May, 1919. The stars in the former were fainter and farther from the sun than those photographed in the latter, and the telescope used was not the best for the work. As for the 1919 eclipse, the star images on the plates giving the lowest deflection of 0″.99 were somewhat out of focus and hence considered untrustworthy; the mean of the two values given by the other plates agrees in magnitude closely with Einstein's predicted value, though the deflection was not directly away from the center of the sun as the theory requires. There is a possibility that refraction in the sun's and the earth's atmospheres have produced some effect, and it is still an open question among scientists whether the results of the 1919 eclipse plates give a real confirmation of the theory. In order to obtain more definite evidence similar photographs were taken with better instrumental equipment during the total eclipse of September 21, 1922, by many different observers. The path of totality passed directly across Australia and over a number of islands adjacent to it; to Wallal, Australia, where the duration of totality was 5 minutes 19 seconds, there were sent five separate expeditions, one from Cambridge, England, one from the University of Toronto, Canada, one from India, one from Perth, West Australia, and the very specially equipped Crocker expedition from the Lick Observatory under the direction of Dr. Campbell. There was also the British expedition, devoted exclusively to testing the Einstein prediction, stationed at Christmas Island, and at this same place was another expedition sent out by Einstein's associates and some amateur astronomers. The observations made by the scientists taking part in these expeditions indicated the presence of a deflection of light that corresponded pretty closely to the deflection predicted by Einstein.

The results of the Canadian expedition were announced as "distinctly confirmatory of the theory," though it was admitted that they could hardly be considered decisive.

The character of the photographs secured by the Lick Observatory expedition was exceptionally good; on each plate there are distinct images of from sixty-two to eighty-five stars. The accurate measurement of the positions of these star images is a task of great delicacy, involving much patient labor extending over many weeks; there were four pairs of plates and it requires fifty hours to make the necessary measurements on each pair, and when all this has been done it still requires many hours of laborious calculations to deduce the amount of deflection of the rays of light indicated by these measurements.

The amount of deflection at the sun's limb as deduced from the measurements made on these plates by Dr. Campbell and Dr. Trumpler is as follows:

	CAMPBELL	TRUMPLER
First pair of plates	1″.72	1″.88
Second pair of plates	1″.35	1″.62
Third pair of plates	1″.78	1″.91
Fourth pair of plates		1″.76

When all these measurements are properly combined, it is found that the value of the deflection of light by the sun, as observed in the 1922 eclipse, is 1″.72 with a probable error of 0″.11, which is in most remarkable agreement with the deflection of 1″.75 predicted by Einstein.

The stars measured for deflection were several diameters removed from the sun's limb. Corrections were made so as to bring these deflections to the limb. These and later observations, after all necessary corrections have been made, are in close agreement with Einstein's predictions.

The total solar eclipse of June 19, 1936, reported by T. Matukuma of Japan in 1940, showed deflections of 2.13 and 1.28 seconds of an arc, with an average of 1.705 ±.425 seconds of an arc. Though the probable error is quite large, this may be regarded as another confirmation of Einstein's relativity theory. Because good plates are hard to obtain, further tests probably will be made.

The following account of a total eclipse is taken from an article written by Dr. S. A. Mitchell, Director, Leander McCormick Observatory, University of Virginia, for the *Americana Annual, 1938*.

"The total eclipse of the sun on June 8, 1937, will go down in history memorable for three separate reasons: first, for the longest duration of totality of any eclipse in 600 years; second, in spite of being in the tropics, the weather was clear during totality at each and every station where there was an expedition; and third, in spite of isolation and long distances, interested persons could ascertain the details of the eclipse preparations quite as well as if they had been close at hand as in the New England Eclipse of 1932. Both the National Broadcasting and the Columbia systems had many coast-to-coast broadcasts.

The National Geographic Society-U. S. Navy Expedition went to Canton Island in the Phoenix group and astronomers from the Hayden Planetarium, New York, went to Peru. The scientific program of the Canton Island party was a well rounded one with many novel features. The instruments were contained in 150 cases. The scientific leader was Dr. S. A. Mitchell.

By the kind of time kept on the island (Honolulu Time) the partial eclipse began at 7:36 A.M. and the total eclipse at 8:36 and lasted 3 mins. 33 secs.

The corona was a very beautiful one, being circular in outline to about one solar diameter from the edge of the dark moon. Beyond there were many long streamers and spikes going off at various angles. To the unaided eye the longest spike extended to two solar diameters, but by protecting the eye from the glare of the sky by looking down a hollow cardboard tube the longest streamers were four diameters. One of the photographs traced this streamer to six diameters or five million miles from the sun's surface. As was expected, with sunspot maximum two years in the future, the corona was of a 'maximum type' or circular in outline. Many prominences of red flames were seen but none of them was conspicuous by its large size.

The total light of the corona was measured by Richtmyer to be approximately half that of the full moon. Polaroid, or the optical substance that cuts down the glare of automobile headlights, was successfully used to measure the polarization of the light of the corona in order to ascertain the manner in which the coronal particles reflect and scatter the light from the sun Charles Bittinger of Washington made an excellent painting of the corona, the canvas being 60 x 60 inches. Dunham of Mt. Wilson Observatory used a spectrograph which was virtually a duplicate of the one on the 100-inch telescope. He obtained successful photographs of the spectrum of the chromosphere and the corona. In the latter spectrum he discovered a new line at wave-length 4412A. Mitchell obtained a photograph of the coronal line at 7892 in the infra-red. In absolute strength this line exceeds 6374 in the red and it is of equal strength with the strong green line at 5303. Mitchell also photographed in the chromosphere more than 25 lines of the Paschen series of hydrogen in the infra-red. In the Balmer series of hydrogen in the visible spectrum he photographed 35 lines.

In Peru, Major A. W. Stevens, U. S. A., obtained photographs of the corona from an airplane at 25,000 feet. The 'globular corona' described by him and the Harvard astronomers has been known for more than 20 years. In a ship at sea, Stewart and Stokley located themselves to obtain the maximum duration of totality which, according to their observations, lasted for 7 mins. 6 secs."

Besides the investigations already outlined above, which evidently depend for their success on a clear sky at the time of totality, certain other observations of a geophysical rather than an astronomical nature may be carried out with equal success in cloudy weather as in clear weather. Among such observations are those directed towards detecting and measuring the possible effects of the eclipse upon the earth's magnetic field and its electrical condition.

LAKE IN GLACIER NATIONAL PARK

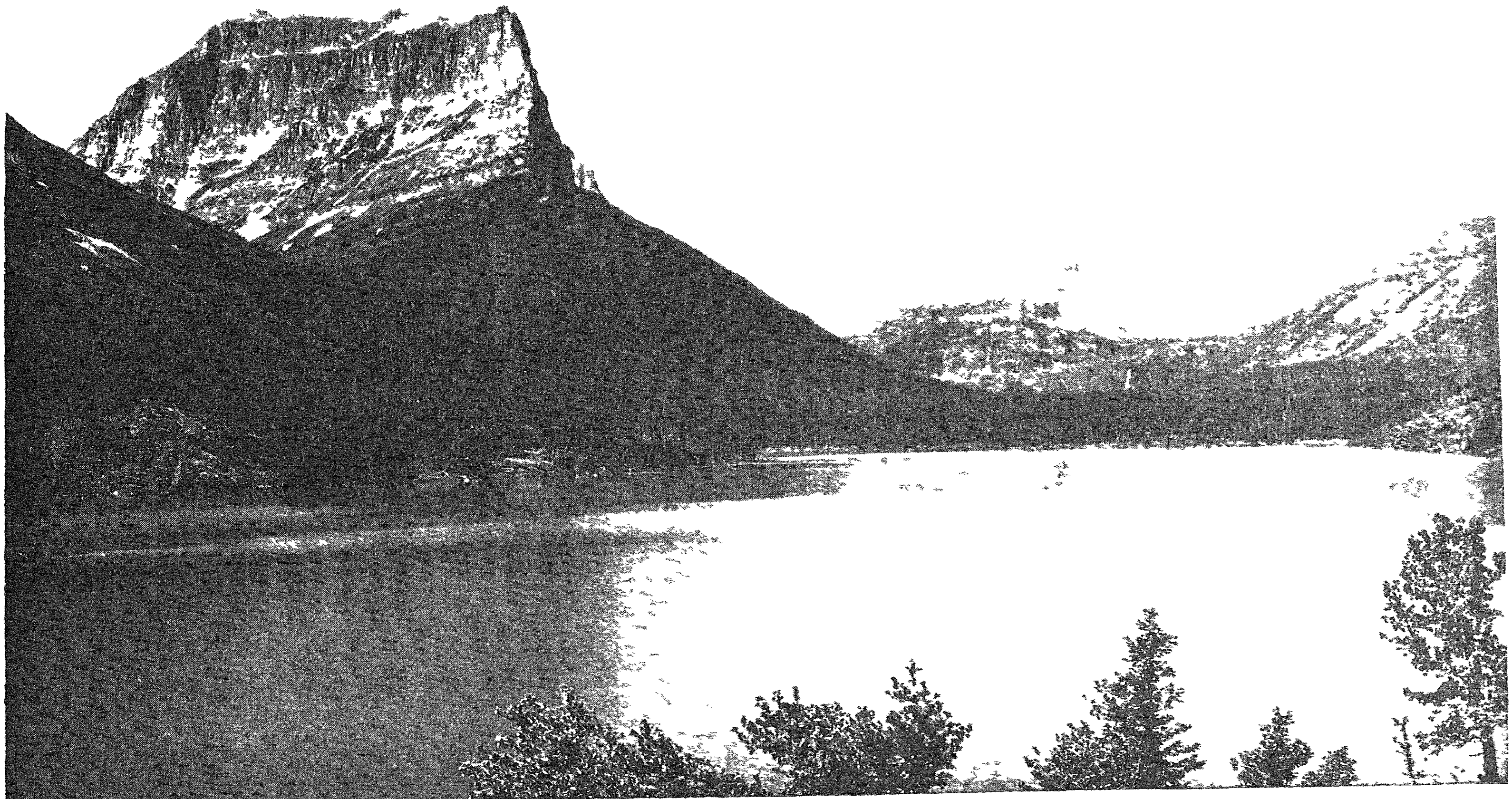


Photo U S Department of the Interior

UPPER ST. MARY'S LAKE, CITADEL, AND FUSILADE MOUNTAINS, FROM THE TRAIL NEAR GOING-TO-THE-SUN CHALETS.

INLAND WATER RESERVES

Past and Present Formation of Lakes and Marshes, and Their Slow Disappearance from the Earth

FEATURES OF THE WORLD'S GREAT LAKES

LAKES are bodies of water collected in basin-like depressions of the land. They are intimately connected with rivers, and not infrequently occur in a chain along a river's course. The beds of the lakes, however, unlike the beds of rivers, are not made by the erosion of running water, the running water finds the beds ready-made, and tends not to deepen them, but to fill them up with silt. If not made by running water, how then are the lake-beds made? Some are craters of old volcanoes; some represent depressions in old boulder-clay deposit, which is always spread very unevenly; some are local subsidences in the land, some have been scooped out by glaciers; some have been caused by barriers across valleys, but most have probably been formed by land movements resulting in the bending up and down of valleys

It will be noticed, therefore, that though running water does not actually make lake-beds, yet in the majority of cases, by the forming of valleys, it prepares the way for the making of lakes, much as it prepared the way for the making of the fiords on the west coasts of Norway and Scotland. Some geologists have considered glaciers the chief agents concerned in the making of lake-beds, but it is probable that the action of glaciers in this way is very limited. When we examine the beds of most lakes, we find that they show signs of sub-aërial, not of glacial, action; and again, when we examine the beds of glaciers, we do not find that they are producing depressions suitable for lakes. Glaciers grind and scratch and polish; they do not gouge and scoop; and though it is quite likely that some small lakes and tarns may have had their beds made for them by glaciers, the beds of such great lakes as the Lake of Geneva, Albert Nyanza and Lugano must have been prepared by actual bendings of the earth's crust, or sometimes, perhaps, by elevations and great subsidences.

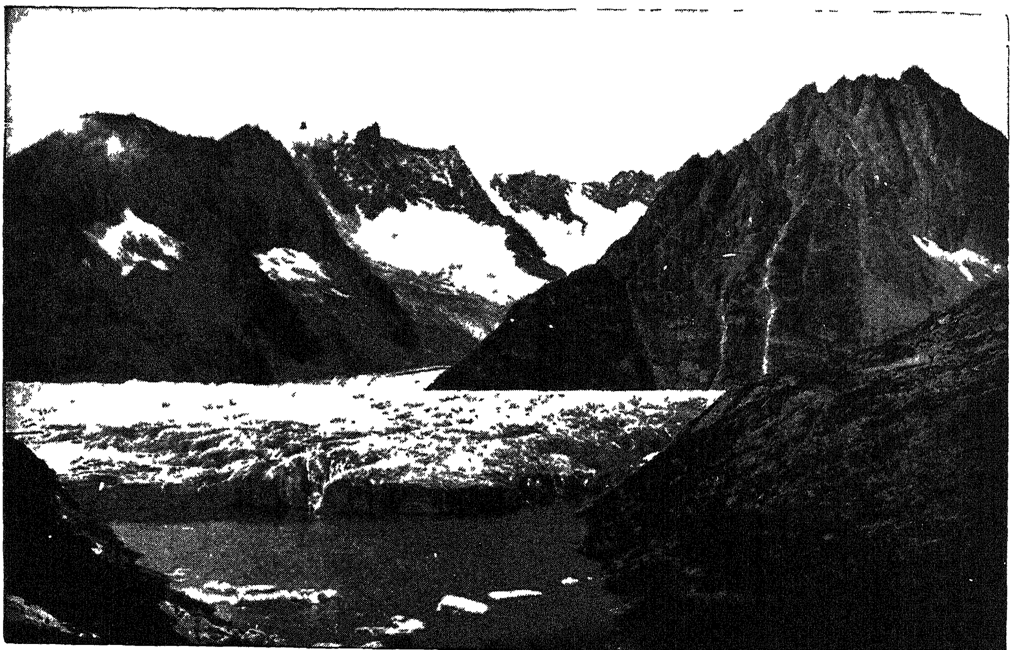
Since earthquakes lower and elevate the land, they often make hollows that become lakes. In 1819, for instance, the Delta of the Indus was shaken by a great earthquake, and the Runn of Cutch, a tract of land including 2000 square miles, subsided, and became an inland sea. After earthquakes in the Mississippi Valley in 1811–1812, about five thousand square miles in Missouri were lowered and converted into lakes and marshes. After the earthquake in Central Japan in 1891 several lakes appeared.

We have said that barriers across valleys sometimes make part of a valley into a lake-bed. A common cause of such a barrier is a landslide. In 1512 the course of the River Blegno, in Switzerland, was dammed by a landslide and a great lake was formed. The Lakes of Derborence were formed by slides from the Diablerets In 1181 a landslide formed a lake 6½ miles long on the plain of Oisans, in the Dauphiny Alps. Villages and forests were submerged, and the inhabitants of the district had to give up farming and take to fishing. After thirty-eight years the lake burst its barrier.

Glaciers sometimes dam river-valleys and form lakes. Thus the ice-dam of the great Aletsch Glacier in Switzerland has formed the Märjelen See. Lakes formed in this way are, of course, far from permanent, and may be suddenly emptied by the bursting of the barrier, or lowered by its gradual melting. In 1818 the Dranse Valley was dammed by a glacier and a large lake gathered, but when attempts were made to drain the lake by tunneling the ice, the ice barrier gave way and fifty people were drowned, and five hundred houses and chalets destroyed. The "parallel roads" of Glen Roy, in Scotland, are supposed to represent the successive levels of a lake which was dammed by a glacier, and which lowered its level as the glacier barrier gave way. In other cases not the glacier itself but its terminal moraine forms the dam which converts part of a valley into a lake bed.

In a few cases the beds of lakes are made by wind. When the surface of the earth consists of shale and is bare of vegetation, the wind gradually scoops out broad, shallow basins, ready to collect rain in the rainy season. Such lake-beds are found on the great plains of the United States. In sandy deserts subject to sudden changes of heat and cold, the wind has still more excavating power, and there are big tracts of the Sahara which have been worn away to below sea level, and may some day become great inland lakes.

In a few cases, also, lakes are formed by banks and bars of sand, thrown up by the currents of the sea along the coast, which eventually cuts off a lagoon from the sea. Though at first containing salt-water, lagoons may eventually contain fresh. An interesting lake is sometimes formed by a loop of a large river when the river changes its course by short-circuiting across the loop. Such loop-lakes are known as "oxbow lakes", and are very common in the basin of the Amazon and along the course of the Mississippi.



THE MÄRJELEN SEE AND THE ALETSCH GLACIER, SWITZERLAND

The table on the next page, showing the height, area and depth of the largest lakes, is given by Dr. H. R. Mill.

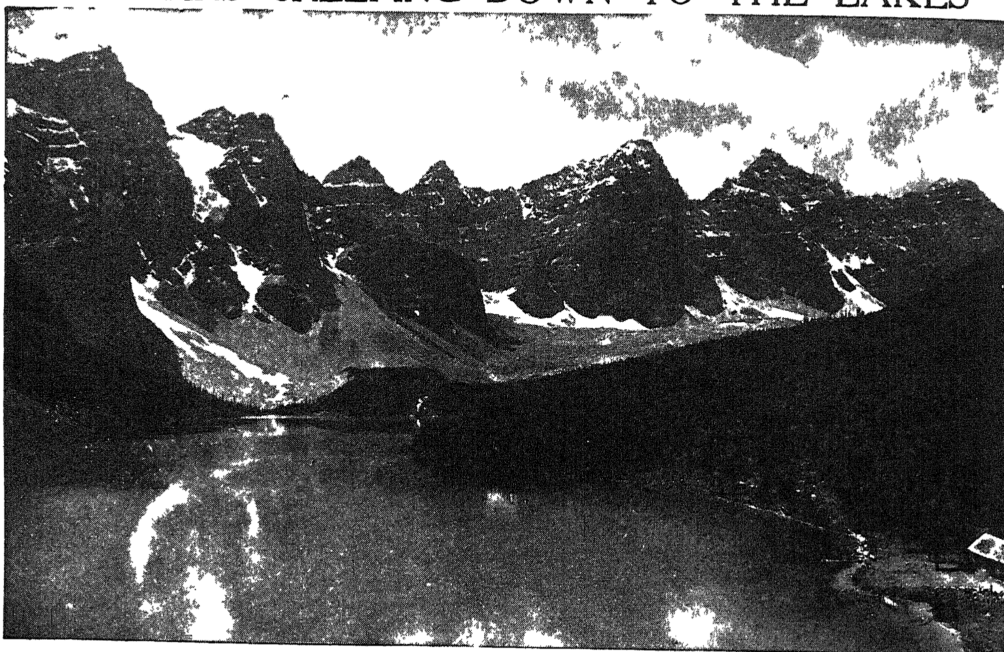
The largest lake in the world is the Caspian Sea; the highest is Askal Chin, in Tibet, which is 16,600 feet above sea-level; the lowest is the Dead Sea, which is 1290 feet below sea-level, and the deepest is Lake Baikal, in Russian Asia, which has a maximum depth of 4800 feet.

THE HEIGHT, DEPTH AND SIZE OF THE SIX LARGEST LAKES IN THE WORLD

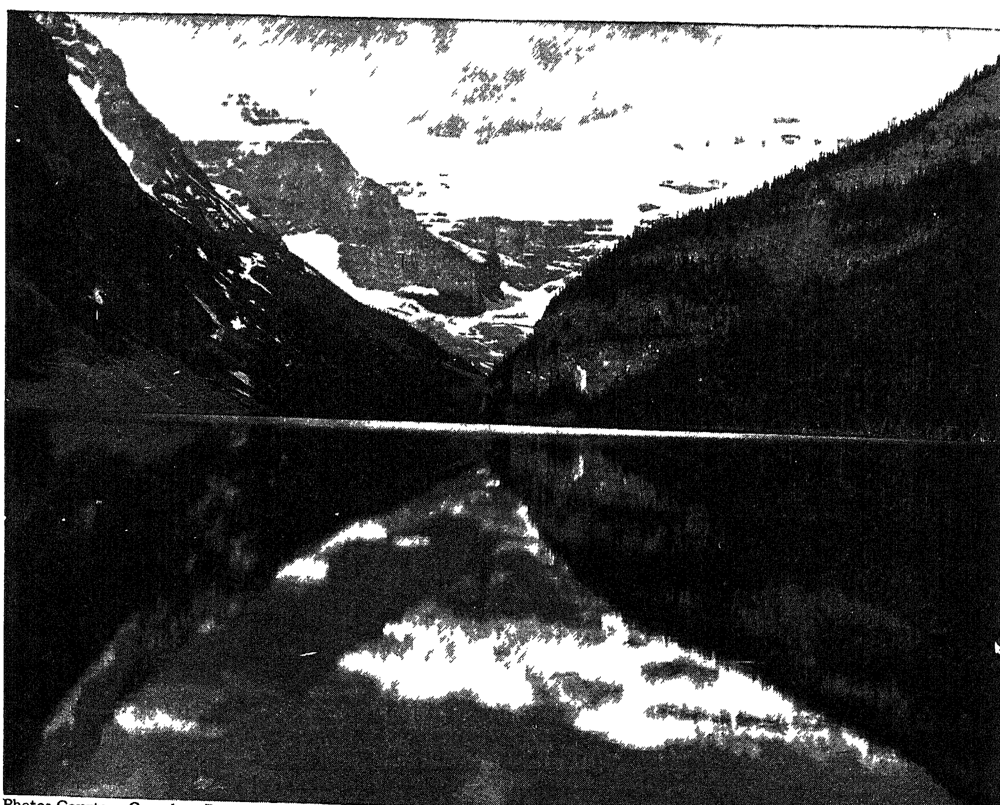
Name	Situation	Height Above Sea in Feet	Area in Square Miles	Maximum Depth in Fathoms
Caspian	Eurasia	90	170,000	500
Superior	North America	600	31,820	215
Victoria	Africa	3,300	26,900	—
Aral	Asia	150	26,200	37
Huron	North America	580	23,010	125
Michigan	United States	580	22,400	154

Many lakes exhibit abrupt transitory changes in level These changes of level are known as "seiches", and may be either local or general. Those of the Lake of Geneva have been studied in great detail by Forel. The water level there rises and falls through a range of several inches with more or less regularity. The motion is an oscillation, an alternate up and down movement that begins suddenly and lasts for some time. During a celebrated seiche in 1600 the water level oscillated through three or four feet. Forel measured these curious changes in level at various points along the shore. He showed from his observations that the seiches consist of a rocking of the whole mass of water of the lake about fixed lines In Lake George, in New South Wales, seiches of the following character have been noticed: "On one occasion, when the lake was very quiet, the water suddenly rose one inch and a half, and fell two inches in three-quarters of an hour; next, it rose two inches, and fell three and a half inches in one hour; finally it rose three and three-quarter inches in forty minutes, and so started a series of pulsations which settled down to two-hour intervals and lasted twenty hours." In the Swiss lakes seiches seem more common by night than by day, and in spring and summer than in winter, and

LAKE MCDERMOTT, GLACIER NATIONAL PARK



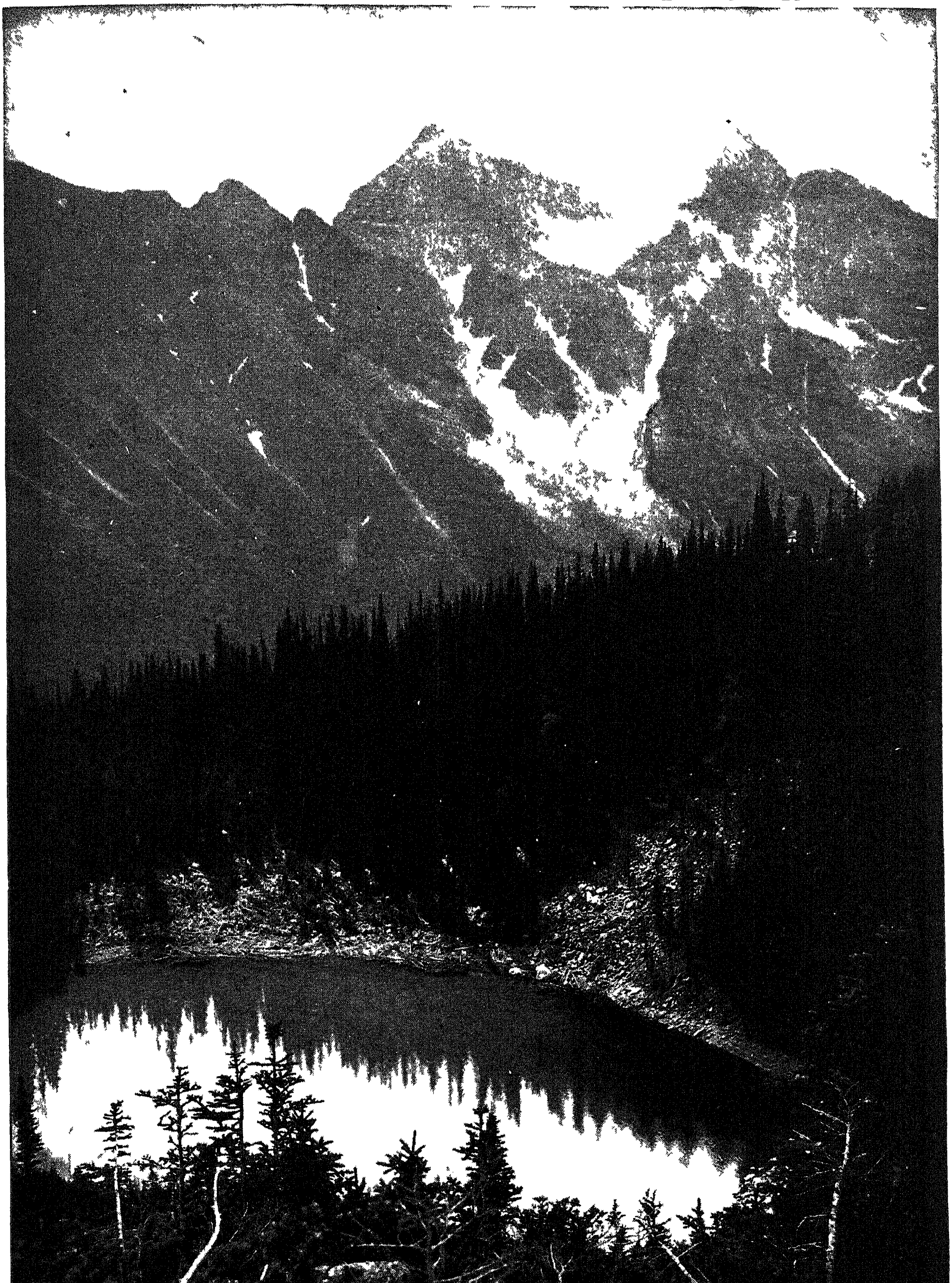
MORAINE LAKE AND TEN PEAKS



Photos Courtesy Canadian Pacific Railway

LAKE LOUISE: THE GREEN MIRROR FOR THE MOUNTAINS AND GLACIERS THAT SURROUND IT

ONE OF THE THREE LAKES IN THE CLOUDS



Courtesy Canadian Pacific Railway

MIRROR LAKE IN THE CANADIAN ROCKIES

they frequently occur when the sun "suddenly begins to shine from amid heavy clouds". In Lake George, on the other hand, seiches are frequently associated with thunderstorms.

As for the cause of seiches it seems clear that they must be due to some agency which heaps up the water of the lake at one end and then ceases to act, thus causing oscillations. Such agencies are minute earthquakes, prolonged winds blowing in one direction and then ceasing rather suddenly and also variations in barometric pressure. Similar seiches which occur in the Baltic have been shown to be connected with variations in barometric pressure.

The temperature of lakes has been carefully investigated, and it has been found that a lake of any depth situated in a temperate country has a mass of cold water which lies along its bottom, and varies little in temperature from month to month. In Loch Lomond, which is about 600 feet deep, the lowest 100 feet of water has a constant temperature of about 42° F., and at the same depth in Seneca Lake, Loch Ness, Loch Oich, Loch Morar, the Lake of Geneva, Lago Maggiore, Lago Lugano and many other lakes the water has about this same temperature.

Lakes perform various geological and climatological functions Like the ocean, they tend to equalize the temperatures of day and night and winter and summer They filter rivers, precipitating soil and salts; the beautiful blue of so many lakes is a proof of their efficiency as filters They furnish an abode for special fauna and flora. But perhaps their most important function is to regulate the supply of river-water to the plains, by serving as reservoirs in time of drought, and by retaining excessive rain in rainy seasons A vast amount of water can pour into a large lake without much raising its general surface, and without much increasing its overflow; and likewise a vast amount of water can be drained from a large lake without much lowering its general surface or diminishing its outflow.

© Ewing Galloway, N. Y.

LAKE PLACID — WITH ITS SUMMER INVASION OF CITY DWELLERS

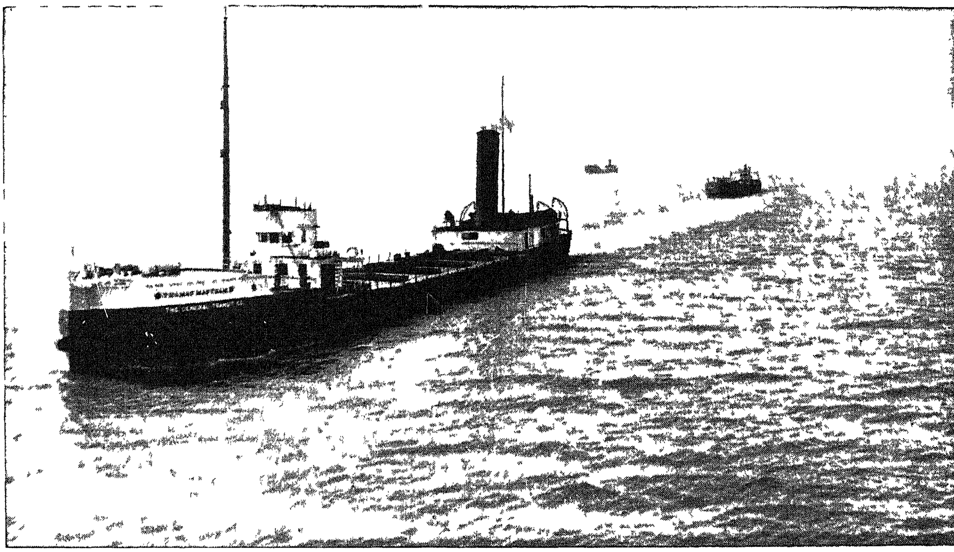
If a river one-tenth of a mile wide flows into a lake one hundred square miles in area, and then continues its course for ten miles to the sea, a rainfall sufficient to raise the level of its last ten miles by twenty-five feet will be intercepted by the lake, and raise the lake's surface only three inches — a rise that will obviously hardly increase its outflow. Reclus shows this regulating action in the case of the Lake of Geneva: "The gauges used at

Geneva establish the fact that the discharge of the Rhône as it issues from the lake is, at its maximum, 753 cubic yards. Now, as the various affluents of the lake supply more than 1400 cubic yards during their highest floods, it is evident that the Lake of Geneva acts as a complete regulator. It keeps back at least one-half of the inundation water, which it subsequently empties down gradually when its tributaries have retired to their usual level. It is certain that, owing to the regulating action exercised over the discharge of the river, the plains on the bank of the middle course of the Rhône, from Geneva to Lyons, are comparatively protected against floods."

From what we have said of the manner of the making of lakes, it is plain that they belong to comparatively recent geological periods, and it is also plain that they have no elements of permanence. The river does not deepen the lake; it fills it up, and in time abolishes the lake altogether; the lake dammed by the glacier will last only as long as the glacier lasts; the lake scooped out of the sand by the wind will very probably be choked; the aigues-mortes will soon become a marsh.

Lakes may contain either salt or fresh water. Some of the salt lakes, such as the Caspian Sea, originally obtained their salt water from the sea, but others, such as the Dead Sea, have collected the salt for themselves from the land. As a rule, lakes with an outlet contain fresh water; without an outlet, salt; but there are exceptions to this rule.

The largest fresh-water lake in the world is Lake Superior, in North America, which is situated 600 feet above sea-level, and covers an area of 31,820 square miles. Lake Victoria Nyanza, in Africa, comes second, covering an area of 26,900 square miles; and Lake Aral, in Asia, is a good third, with an area only slightly less.



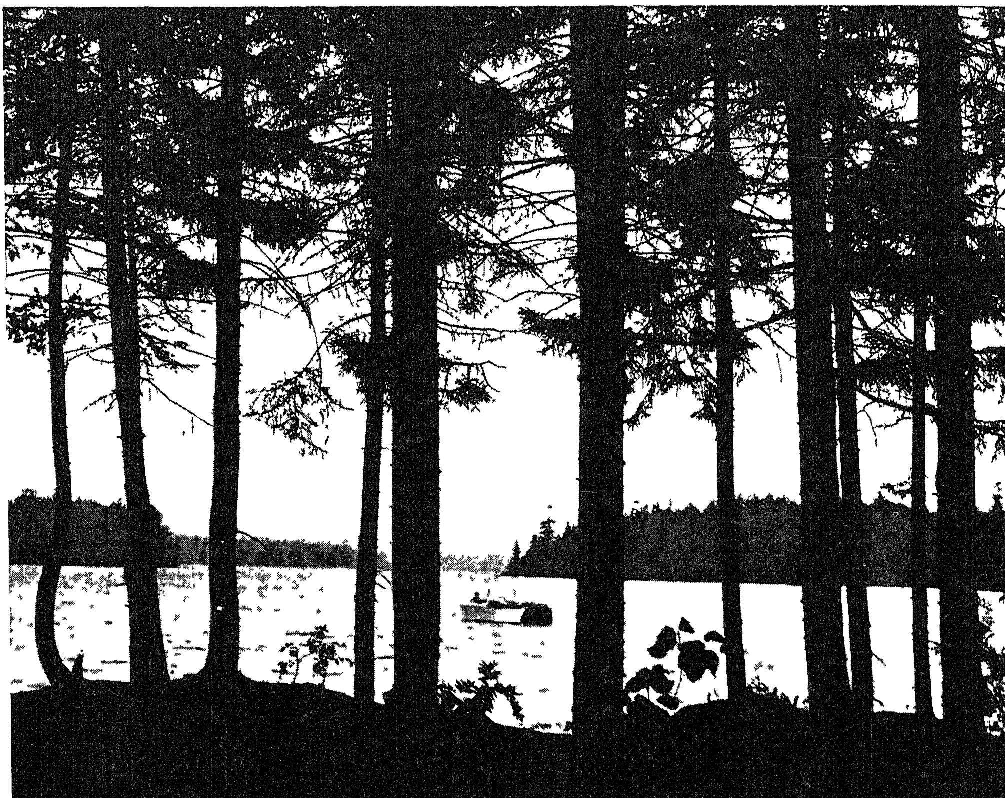
LAKE SUPERIOR — AN INLAND OCEAN'S LIMITLESS HORIZON

Then come Lake Huron and Lake Michigan, respectively 23,010 and 22,400 square miles in area. The five great North American lakes, Superior, Michigan, Huron, Erie and Ontario, together cover an area of 94,710 square miles — an area, that is to say, about the same size as England. Big as the Great Lakes are, there is geological evidence which indicates that a still bigger lake formerly existed — a lake 700 miles long from north to south, and covering an area of about 110,000 square miles. All that is left now of this tremendous lake is a few sheets of water scattered here and there, but there can be no doubt of its former existence, and it

has been named by geologists "Lake Agassiz". At one time, too, both Lake Superior and Lake Huron were larger and deeper than they now are, as is shown by the series of raised shingle beaches that form terraces round their shores.

The salt lakes are particularly interesting. As we have said, there are two classes of salt lakes — salt lakes that derive their salt from the sea, and salt lakes that derive their salt from the rivers that drain into them. Salt lakes of marine origin have been cut off from the parent sea by movements of the earth's crust. They are not very numerous, and they tend to dry up. The largest and most typical is the Caspian Sea. It covers an area of 170,000 square miles, and is therefore almost six times as large as Lake Superior, and almost twice as large as the combined area of the five great North American lakes. It is not only large — it is also deep; its maximum depth is 3000 feet, which is more than three times the depth of Lake Superior.

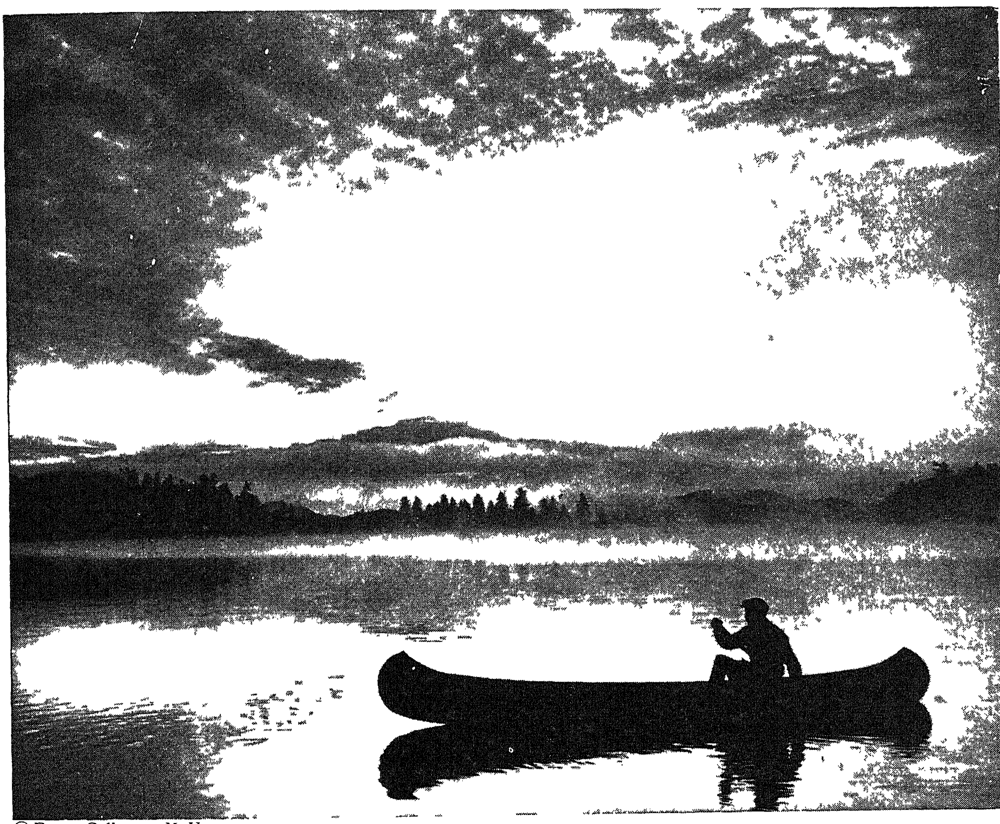
At one time this great lake was certainly continuous with the Black Sea, for between the two is a chain of salt lakes and marshes. Also, the shells in the Caspian Sea are the same as the shells in the Black Sea, and banks of similar shells stretch between the two seas. It seems probable, too, that at one time a great arm of the Caspian Sea stretched northward over the steppes of southeastern Russia, even as far as the Arctic Sea, since in that direction there are still salty plains and little salt lakes, and since seals which seem a variety of the Arctic species are found in the Caspian Sea. It is strange to think that a lake so far to the south should have seal fisheries, yet the seal fisheries of the Caspian Sea are a big and flourishing industry.



FULTON CHAIN LAKES, ADIRONDACKS — LOOKING THROUGH THE PINES

At present the surface of the Caspian is about 90 feet below sea-level, the fall being due partly to the movements of the earth's crust and partly to evaporation. The present influx of water to the lake about balances evaporation, but the surface of the Sea of Aral, which once joined the Caspian, is slowly sinking year by year. Were the Caspian to fill up again to sea-level it would flood several hundred thousand square miles of the steppes Since the rivers constantly add salt to the Caspian, and since evaporation prevents any increase of water, one would expect the Caspian to be excessively salt, and it is rather surprising to find that on the average it is not so salt as the general ocean, and not even so salt as the Mediterranean. How is this? The reason of this apparent anomaly is that "the shelving shores, and particularly the wide, shallow inlet of Kara-Baghas, act as natural salt-pans, evaporating the thin layer of water covering them and causing a deposit of crystalline salt, which is thus being gradually withdrawn from solution, while evaporation is made good by a continual supply of fresh water".

In the Kara-Baghas itself, which is an offshoot of the Caspian Sea, the waters are much salter, and it has been estimated that every day 350,000 tons of salt are swept into it through the shallow inlet. So salt has the Kara-Baghas become that the seals have left it, and no vegetation will grow on its banks Still salter is the arm of the sea called Karasu, where the salinity rises to 5.7 per cent. All round the Caspian Sea there are shallow salt pools and lagoons where salt is concentrated and deposited. "One basin," says Reclus, "still occasionally receives water from the sea, and has deposited on its banks only a very thin layer of salt. A second, likewise full of water, has its bottom



© Ewing Galloway, N Y

EARLY MORNING MISTS ON BIG MOOSE LAKE

hidden by a thick crust of rose-colored crystals like a pavement of marble. A third exhibits a compactness of salt, in which glitter here and there pools of water situated more than a yard below the level of the sea. Lastly, another has lost by means of evaporation all the water which once filled it, and the strata of salt which carpets its bed are partly covered by sand."

The Dead Sea is a yet more famous lake, famous both because of its salinity and because of the depth of its surface below sea-level. It lies no less than 1290 feet below the level of the Mediterranean, and the predominant salt is not chloride of sodium, or common salt, as in the case of the Caspian Sea, but chloride of magnesium. It has 15.9 per cent of chloride of magnesium, and only 3.6 per cent of sodium chloride. It is probably the large percentage of magnesium chloride that renders the water so destructive to life. Though the Dead Sea must at one time have approached the Red Sea, it is unlikely that it communicated with it, since no trace of iodine is found in the water of the latter, and the foraminifera in the mud of the former do not belong to Red Sea species.

To the west of the Caspian lies Lake

THE DEAD SEA, WHICH IS GRADUALLY INCREASING IN DEPTH

is fed by the Jordan, which enters at its north end and finds no exit. The sea now covers an area of only 460 square miles, but there are layers of marl and beds of salt on the slopes surrounding it, and it is probable that at one time it stretched from the foot of Lebanon to the north of the Red Sea. The lake well deserves the adjective "dead", for no fish live in its waters, and no vegetation grows on its banks. Its salinity is much greater than the salinity of the Caspian Sea, and eight or nine times as great as the salinity of the ocean and its salt content differs greatly from the salt content of the ocean. It contains about 25 per cent of salts, but

Elton, a very saline lake, whose bed consists of layers of salt constantly thickening from year to year. In summer, when evaporation is rapid and the lake diminishes in size, its shores look like immense, glistening snowfields.

In the northwestern part of Utah lies the Great Salt Lake with an area of about 2000 square miles and an average depth of 20 feet. The water is extremely salty, resembling ocean water in composition but nearly six times as dense, containing about 18 per cent of solids. According to Gilbert the lake holds about 400,000,000 tons of sodium chloride, common salt, and 30,000,000 tons of sodium sulphate.

These are the main solids in solution. So dense is the water that it is buoyant to float in, but very difficult to swim in, and it is so acrid that if it gets into one's eye it causes great pain, and inhalation of the spray causes a spasm of coughing.

The only living things in the lake are small worms that burrow in the sand of the shore, and a seaweed of the Nostoc species, and on the shores of the lake only such shrubs are found as can tolerate a saline soil.

At present rainfall and evaporation about balance each other, and the lake preserves a more or less constant level, and neither increases nor diminishes, but, like most other salt lakes, it has known better days. It is, indeed, merely a remnant of a greater lake, an inland sea, as large as Lake Michigan, 20,000 square miles, and over 1500 feet deep, to which the name of Lake Bonneville has been given. This great original lake was a fresh-water lake, and drained into the Pacific by the Snake and Columbia Rivers: its beaches and shore terraces can still be traced along the slope of the surrounding mountains. To the west of this great lake there was a second fresh-water lake almost as large, now called by geologists Lake Lahontan, also draining into the Pacific. As meteorological or geological conditions changed, and these lakes dried up, they became more and more saline, and the deserts of the Great Basin are largely due to the precipitation of salts from the retreating lakes.

The table below, collated from tables given by Geikie and Bonney, shows the comparative saltness of various lakes and seas.

Many rocks have been formed by the precipitation of salts from lake and sea water. The least soluble salts are the first to be precipitated. Evaporation of lake water having a composition resembling sea water would result in a precipitation of gypsum (calcium sulphate), followed by a precipitation of rock salt, and this order is found in saliferous formations. In the case of the Dead Sea, and Lake Elton, and other lakes where the most plentiful salt is the chloride of magnesium, large amounts of chloride of sodium have already been precipitated; and if more chloride of sodium is added to water containing large quantities of chloride of magnesium, the chloride of sodium is precipitated. Hence, when the Jordan brings down additional chloride of sodium to the Dead Sea, the salt is quickly precipitated. The bottom of the Dead Sea, accordingly, consists of common salt and gypsum mixed with mud.

As we have already said, most lakes tend to be filled up. In the course of such filling up they are converted into a marshy condition, and many marshes are simply half-dried lakes. Not infrequently a lake full of water in the rainy season may dry up partially and become a marsh in the dry season. But marshes also originate in other ways. Along the course of rivers subject to overflowing which traverse low-lying land there are always swamps and marshes; and if the river be large it may form correspondingly large swamps and marshes. Even apart from overflowing rivers, any great stretches of level land become marshes if there be sufficient rainfall. The great plains of Brazil crossed by the Paraguay and its tributaries exhibit a

THE SALTNESS OF LAKES, EXPRESSED IN PARTS PER THOUSAND

Deposit	Great Salt Lake	Caspian at Baku	Elton Lake	Dead Sea	English Channel
Chloride of Sodium	118.628	85.267	38.3	36.372	27.059
Chloride of Potassium	.862	Trace	2.3	8.379	.765
Chloride of Magnesium	14.908	03.039	197.5	159.774	3.666
Chloride of Calcium	—	—	—	47.197	—
Sulphate of Magnesium	—	32.493	53.2	—	2.295
Sulphate of Calcium	.858	10.742	—	0.889	1.406
Sulphate of Sodium	9.321	—	—	—	—
Sulphate of Potassium	5 363	—	—	—	—
Carbonate of Calcium	—	00.554	—	—	.033
Bromide of Magnesium	—	—	—	8.157	.029

series of immense marshes. Lake Tchad, in Africa, is so surrounded by bogs that its true dimensions cannot be defined. Where the ground is rich in decayed vegetation the marshes are known as peat-mosses, or bogs, and these are specially interesting as the factories where coal is prepared for future generations. There are hundreds of thousands of acres of bogs in Germany, Sweden, Norway, England, Scotland, Holland, France and Denmark. In Russia it is thought that the bog area exceeds four and a quarter million acres. One-seventh of the whole area of Ireland is covered with peat-bogs; the Bog of Allen alone comprises no less than 238,500 acres with an average depth of 25 feet. In Canada and the United States there are enormous peat formations, careful estimation making the area of swamps, bogs and inundated land in the latter over 60,000,000 acres.

In peat formation vegetable decay, largely due to bacterial action, is stopped by the non-removal of bacterial waste products which make the peat liquids an excellent preservative. This antiseptic quality of peat bogs is well shown in the preservation of bodies of men and animals entombed in them hundreds and probably thousands of years ago. The reclamation of bogs for farming purposes involves draining and plowing up the soil to permit the neces sary oxidization processes. Oats are usually the first crop, but, once reclaimed, the soil is very fertile and is especially adapted for the growth of vegetables like celery, onions and the various roots.

Some of the greatest marshes of the world are the salt-water marshes on the shores of the sea. Along the coast of Florida a belt of marsh five to twenty miles wide stretches for many miles. These marshes are often known as mangrove swamps, because they are covered with thick jungles of mangrove trees, which have bird-nests on their branches and crabs and barnacles among their roots. Along the shores of the Gulf of Mexico there are millions of acres of marshes covered not with mangroves but with cypresses, and these, again, are known as "cypress swamps". For centuries it was believed that swamps and marshes gave off poisonous vapors that caused malaria, but it is now known that the malaria is not due to poisonous vapors, but to a tiny animal organism carried by mosquitoes from infected to healthy persons.

A MANGROVE SWAMP IN THE MALAY STATES

A GREAT LEADER

The Work of Dr. Bateson, the Master and Founder of the School of Genetics

THE ANALYSIS OF FORMATIVE UNITS

IN our study of heredity we have found our science so young and so rapidly developing that it was best to deal with it under the names of a few great students; and, having discussed in turn the work of Galton, Weismann, Mendel and De Vries, we come now to the figure of one of the greatest leaders in this fertile and almost virgin field of science. Professor William Bateson, F.R.S., was the first holder of the chair of biology established at Cambridge University in honor of Darwin. He retired from that chair in order to have more time for research, and became director of the John Innes Horticultural Institution at Merton, in Surrey, and later professor of physiology at the Royal Institution. He died February 8, 1926.

Professor Bateson became the leader of the Mendelian school, the present achievements of which will afterwards, and for long afterwards, concern us. But his preparation for this study began earlier than the present century, and requires our understanding here. We must go back over thirty years, to the publication of his great book, now looked upon as a classic by biologists, which is modestly entitled "Materials for the Study of Variation", and which was published in 1894. The title is modest indeed, but if we think a moment we shall see that it conveys rather more than meets the ear. In fact, it is "a summons and a challenge".

When it appeared, biologists were, for the most part, in a somewhat hypnotic, not to say cataleptic, state, under the influence of Darwin. Herbert Spencer was protesting against the uncritical acceptance of "the all-sufficiency of natural selection", but, as he held no degree and had never passed an examination, of course his observations could be discounted. Hence the title of Dr. Bateson's book was startling, for it seemed to suggest what we now see to be so exceedingly true — that the study of variation had at that time practically not even begun, and that the first necessity was for the collection of exact facts. What this meant and means for Darwinism, or for any other special theory of organic evolution, we can see at once, if we remember that variations are the very material and essential of all evolution, and that, in reality, the study of evolution is the study of variations. Everyone was supposing that evolution had been explained, once and for all. Darwin's remains were in the Abbey, and then there appeared this book, which suggested that, in time, we might be ready to begin at the beginning.

When the natural selection of minute chance variations of living creatures is felt to be an inadequate explanation of the facts of living nature, we ask ourselves — or, rather, Dr. Bateson asked himself — whether there are not other kinds of variation, that do occur not infrequently, and that might far more probably furnish the beginnings of new species. The conclusion to which he came is that there are two distinct kinds of variation, to which he gave the name of continuous and discontinuous variation respectively. The former is universal and illustrated by every living creature, and it is this type of variation in which the theory of Darwin sees the material for natural selection to act upon.

But the conclusion at which Dr. Bateson arrived, as long ago as 1894, was that the very grave difficulties in the way of accepting this theory may be avoided if we turn to the facts of discontinuous variation. In sum, he showed "(1) that differences of the kind which are generally used to distinguish separate species may arise as single variations; (2) that such a form of variation is by no means so uncommon a phenomenon as was formerly supposed: and (3) that variations of this kind may occur in every description of organ and part, in a number of different plants and animals".

We see at once, of course, that there is a substantial identity between the view of Bateson, that organic evolution depends upon discontinuous variations, and the "mutations theory" of De Vries, which we have already studied. And naturally an author who had already come to these conclusions was prepared for the rediscovery of Mendel's paper half a dozen years later. He saw at once that we now required an experimental science, which should begin at the beginning, and try to ascertain the precise facts of heredity and variation, with the aid of the long-lost key which Mendel had provided. Biologists had neglected this essential task. As Dr. Bateson himself says: "Darwin's achievement so far exceeded anything that was thought possible before, that what should have been hailed as a long-expected beginning was taken for the completed work."

Genetics a contribution to the advancement of pure physiological science

Nevertheless, Dr. Bateson founded the science of genetics, primarily "in the hope that it would elucidate the problem of species". But, in the course of the last few years, the possibilities of these experiments have become greatly extended. Here is Dr. Bateson's own statement: "The time has now come when appeals for the vigorous prosecution of this method should rather be based on other grounds. It is as directly contributing to the advancement of pure physiological science that genetics can present the strongest claim. We have an eye always on the evolution problem. We know that the facts we are collecting will help in its solution, but for a period we shall perhaps do well to direct our search more especially to the immediate problems of genetic physiology, the laws of heredity, the nature of variation, the significance of sex, and other manifestations of dimorphism (*i.e.*, 'two-form-ism'), willing to postpone the application of the results to wider problems as a task more suited to a maturer stage. When the magnitude and definiteness of the advances already made in genetics come to be more generally known, it is to be anticipated that workers in various departments of biology will realize that here at last is common ground."

The truth is that experimental breeding is the only way in which we can learn many facts about individuals and their composition and constitution. Genetics was founded, as its name implies, in order to define and study the problems of genesis. But now we discover that in studying these problems we find the clue to all manner of questions which general physiology is interested in. Nothing, for instance, is more interesting for biology in general than the nature of sex.

Genetic experiment began by assuming the fact of sex, of course, and proceeding to observe the consequences of bi-sexual reproduction; but it goes on to see that sex itself is a characteristic which may be studied genetically, just like eye-color. We find that the sex of an individual is one of its features, dependent, like other features, upon certain "factors", or "determinants", in the germ-cells whence it was formed. We learn, too, how strangely this factor of maleness or femaleness affects other characters which are transmitted and represented in the germ-cells beside them, so that if the factor for maleness be present along with the factor which gives rise to what is called the "bleeding disease", the boy will be a "bleeder", but if femaleness and the factor for this disease come together, the girl is *not* a "bleeder", though her sons may be. This is a mere illustration to show how entirely the claim of Dr. Bateson is justified when he suggests that these inquiries are of interest to far more students than those of heredity alone.

Novel and invaluable contributions to the chemistry of physiology

One other illustration of his contention may be referred to. There is a department of science called "physiological chemistry", which studies the chemistry and chemical interactions of the different parts of living bodies. But this science has hitherto been quite unable to throw any light upon the development of the adult body from the germ, though plainly there must be plenty of chemical problems involved therein. Here genetics, with its new method, and its unprecedented angle of attack upon standing physiological problems, makes novel and invaluable contributions. The study of the inheritance of the colors of sweet-peas, for instance, shows how such and such a color may be altered into another by the addition of a special "factor" to the germ-cells. But when we ascertain that the second color is simply an oxidation product of the first, naturally we surmise that the extra factor in the germ-cells which made the difference must be of the nature of an oxidizing ferment. Thus the standing ideas of the architecture of the body and the corresponding architecture of the germ-plasm, so much discussed by Weismann, come to be supplemented by ideas of the chemistry of the body, and the corresponding chemistry of the germ-plasm; and we begin to suspect that these latter ideas are the deeper of the two.

Dr. Bateson's definition of genetics — the physiology of heredity and variation

But this is a case where no exposition by others is required, for we have Dr. Bateson's own words to draw upon; and the best service the writer can perform, for the reader and for genetics, is to present in brief, but with some exact citations, the arguments and the conclusions embodied in Dr. Bateson's inaugural lecture as professor of biology in the University of Cambridge on "The Methods and Scope of Genetics", and we may consider it now in the light of the subsequent knowledge gained in the intervening years. In introducing that lecture Dr. Bateson defines genetics as "the physiology of heredity and variation", and states his belief that "genetic research is still pushing forward in the central undifferentiated trunk of biological science", thanks to "Mendelian discovery leading us into a new world, the very existence of which was unsuspected before".

The two-cell production of all ordinary forms of life, and its consequences

We start from the familiar fact that all the ordinary animals and plants begin their individual lives by the union of two cells, the one male, the other female. "Now, obviously the diversity of form which is characteristic of the animal and plant world must be somehow represented in the gametes, since it is they which bring into each organism all that it contains. . . . The fact that *two* cells are concerned in the production of all the ordinary forms of life was discovered a long while ago, and has been part of the common stock of elementary knowledge of all educated persons for about half a century. The full consequences of this double nature seem nevertheless to have struck nobody before Mendel. . . . We are accustomed to think of a man, a butterfly, or an apple-tree as each *one* thing. In order to understand the significance of Mendelism we must get thoroughly familiar with the fact that they are each *two* things, double throughout every part of their composition. . . . That we are assemblages or medleys of our parental characteristics is obvious. We all know that a man may have his father's hair, his mother's color, his father's voice, his mother's insensibility to music, and so on, but that is not enough.

"Such an analysis is true, inasmuch as the various characters *are* transmitted independently, but it misses the essential point. For in each of these respects the individual is double; and so to get a true picture of the composition of the individual we have to think how *each* of the two original gametes was provided in the matter of height, hair, color, mathematical ability, nail-shape and the other features that go to make the man we know. The contribution of each gamete in each respect has thus to be separately brought to account."

Pure breeding and cross-breeding according to germ-cell ingredients

"If we could make a list of all the ingredients that go to form a man, and could set out how he is constituted in respect to each of them, it would not suffice to give one column of values for these ingredients, but we must rule two columns, one for the ovum and one for the spermatozoön, which united in fertilization to form the man, and in each column we must represent how that gamete was supplied in respect to each of the ingredients in our list. When the problem of heredity is thus represented we can hardly avoid discovering, by mere inspection, one of the chief conclusions to which genetic study has led. For it is obvious that the contributions of the male and female gametes may in respect to any of the ingredients be either the same or different. In any case in which the contribution made by the two cells is the same, the resulting organism — in our example the man — is, as we call it, *pure bred* for that ingredient, and in all respects in which the contribution from the two sides of the parentage is dissimilar the resulting organism is *cross-bred.*"

We have already learned that in the Mendelian analysis there occur the terms "dominant" and "recessive" to describe characters which appear or do not appear, characters which are patent or latent in any individual. This contrast is not an essential part of Mendelism, but it is very notable, and needs explanation. The now accepted view of its cause is called the "presence or absence hypothesis", which was framed by Professor Bateson, and which he describes in the following words:

"We have got to the point of view from which we see the individual made up of a large number of distinct ingredients, contributed from two sources, and in respect to any of them he may have received two similar portions or two dissimilar portions. We shall not go far wrong if we extend and elaborate our illustration thus.

"Let us imagine the contents of a gamete as a fluid made by taking a drop from each of a definite number of bottles in a chest containing tinctures of the several ingredients. There is one such chest from which the male gamete is to be made up, and a similar chest containing a corresponding set of bottles out of which the components of the female gamete are to be taken. But in either chest one or more of the bottles may be empty; then nothing goes in to represent that ingredient from that chest; and if corresponding bottles are empty in both chests, then the individual made on fertilization by mixing the two collections of drops together does not contain the missing ingredient at all. It follows, therefore, that an individual may thus be 'pure bred' — namely, alike on both sides of his composition — as regards each ingredient in one of two ways, either by having received the ingredient from the male chest and from the female, or in having received it from neither. Conversely, in respect to any ingredient he may be 'cross-bred', receiving the presence of it from one gamete and the absence of it from another."

The interplay of qualities in one parent or both, a prime conception

"The second conception with which we have now to become thoroughly familiar is that of the individual as composed of what we call presences and absences of all the possible ingredients. It is the basis of all progress in genetic analysis. . . . A blue eye is due to the absence of a factor which forms pigment on the front of the iris. Two blue-eyed parents, therefore, as Hurst has proved, do not have dark-eyed children. The dark eye is due to either a single or a double dose of the factor missing from the blue eye. So dark-eyed persons may have families all dark-eyed, or families composed of a mixture of dark and light eyed children in certain proportions which on the average are definite."

Plainly, the reason why the dark-eyed people may have two kinds of families is that the dark or brown eye may be "pure", its possessor having received the presence of the factor from both parents, or "impure", its possessor having received the presence of the factor from one parent and the absence from the other. Brown is

dominant over blue because, on Professor Bateson's theory, brown is due to the presence of something the absence of which makes a blue eye; hence, if the brownness comes from one parent and the blueness (which is merely the absence of brownness) from the other, the offspring will have brown eyes, and we say that brown is dominant over blue. The "presence and absence hypothesis" beautifully explains this and a host of similar cases. But we cannot do better than quote Dr. Bateson himself. Having shown the double origin of constitution of the individual, and what it means, he proceeds to the next question:

The phenomenon which is the essence of Mendel's discovery

"So far we have been considering the synthesis of the individual from ingredients brought into him by the two gametes. In the next step of our consideration we reverse the process, and examine how the ingredients of which he was originally compounded are distributed among the gametes that are eventually budded off from him.

"Take first the case of the components in respect of which he is pure bred. Expectation would naturally suggest that all the germ-cells formed from him would be alike in respect of those ingredients, and observation shows, except in the rare cases of originating variations, the causation of which is still obscure, that this expectation is correct. . . . But when we proceed to ask how the germ-cells will be constituted in the case of an individual who is cross-bred in some respect, containing, that is to say, an ingredient from the one side of his parentage and not from the other, the answer is entirely contrary to all the preconceptions which either science or common sense had formed about heredity. For we find definite experimental proof, in nearly all the cases which have been examined, that the germ-cells formed by such individuals do either contain or not contain a representation of the ingredient, just as the original gametes did or did not contain it. If *both* parent-gametes brought a certain quality in, then all the daughter-gametes have it; if neither brought it in, then none of the daughter-gametes have it. If it came in from one side and not from the other, then on an average in half the resulting gametes it will be present and from half it will be absent. This last phenomenon, which is called segregation, constitutes the essence of Mendel's discovery. . . . It is this fact which entitles us to speak of the purity of germ-cells. They are pure in the possession of an ingredient, or in not possessing it; and the ingredients, or factors, as we generally call them, are units because they are so treated in the process of formation of the new gametes, and because they come out of the process of segregation in the same condition as they went in at fertilization."

Rules that are exemplified in heredity with remarkable exactness

"As a consequence of these facts it follows that, however complex may be the origin of two given parents, the composition of the offspring they can produce is limited. There is only a limited number of types to be made by the possible recombinations of the parental ingredients, and the relative numbers in which each type will be represented are often predicable by very simple arithmetical rules. For example, if neither parent possesses a certain factor at all, then none of the offspring will have it. If either parent has two doses of the factor, then all the children will have it; and if either parent has one dose of the factor and the other has none, then on an average half the family will have it and half be without it. . . . In such an observation two things are strikingly exemplified: (1) the fact of the permanence of the unit; and (2) the fact that a *mixture* of types in the family means that one or other parent is cross-bred in some respect, and is giving off gametes of more than one type."

Questions put to nature in her hidden world of life's renewal

"The problem of heredity is thus a problem primarily analytical. We have to detect and enumerate the factors out of which the bodies of animals and plants are built up, and the laws of their distribution among the germ-cells. All the

processes of which I have spoken are accomplished by means of cell-divisions, and in the one cell-union which occurs in fertilization. If we could watch the factors segregating from each other in cell-division, or even if by microscopic examination we could recognize this multitudinous diversity of composition that must certainly exist among the germ-cells of all ordinary individuals, the work of genetics would be much simpler than it is.

"But so far no such direct method of observation has been discovered. In default we are obliged to examine the constitution of the germ-cells by experimental breeding, so contrived that each mating shall test the composition of an individual in one or more chosen respects, and, so to speak, sample its germ-cells by counting the number of each kind of offspring which it can produce. But cumbersome as this method must necessarily be, it enables us to put questions to nature which never have been put before. She, it has been said, is an unwilling witness. Our questions must be shaped in such a way that the only possible answer is a direct Yes or a direct No. By putting such questions we have received some astonishing answers which go far below the surface. Amazing though they be, they are nevertheless true; for though our witness may prevaricate, she cannot lie. Piecing these answers together, getting one hint from this experiment, and another from that, we begin little by little to reconstruct what is going on in that hidden world of gametes."

The complexity of the arrangements by which some qualities are produced

Very early in these studies we discover that by no means all the characteristics of living creatures are due to the presence or absence of a single factor from their constitution. There are many features which require the concurrence of several factors to produce them; nevertheless, though the character appears only when all the complementary ingredients are together present, each of these severally and independently follows, as regards its transmission, the very simple rules we have already described.

Thus, for instance, there are two dwarf varieties of sweet-pea, the "Cupid" and the "bush", which, when crossed together, yield offspring of full height. As Professor Bateson says, "There is thus some element in the Cupid which, when it meets the complementary element from the bush, produces the characteristic length of the ordinary sweet-pea. We may note in passing that such a fact demonstrates at once the nature of variation and reversion. The reversion occurs because the two factors that make the *height* of the old sweet-pea again come together after being parted; and the variations by which each of the dwarfs came into existence must have taken place by the dropping out of one of these elements or of the other."

The repulsions as well as attractions that exist among the genetic ingredients

But the various Mendelian factors may have other mutual relations. The presence of one will often prevent or inhibit the development and appearance of another. Thus the factor for sex may prevent the appearance of certain characters, say in a female, though the factors for those characters are also present. Or, again, all the factors for the production of color may be present in a plant or an animal, but there may be a further factor present which keeps the individual white. If that one factor can be bred out, then the color will appear. Again, to quote Bateson:

"There are cases in which the action of factors is superposed one on top of the other, and not until each factor is removed in turn can the effects of the underlying factors be perceived. So in the mouse, if no other color-factor is present, the fur is chocolate. If the next factor in the series be there, it is black. If still another factor be added, it has the brownish-gray of the common wild mouse. Conversely, by the variation which dropped out the top factor, a black mouse came into existence. By the loss of the black factor, the chocolate mouse was created, and, for aught we can tell, there may be more possibilities hidden beneath."

Similarly, experiment shows that in many instances there is an antagonism or

repulsion between certain factors, so that if one of them goes into a germ-cell, the other never does, and thus an individual having the combination of the two characters in question cannot exist. This is illustrated in such organisms as sweet-peas, but it is also capable of illustration in the almost innumerable types of human nature. Human abnormalities, also, such as color-blindness, illustrate a further possibility. This condition is apparently due to the presence of some positive ingredient which affects the sight. "Just as nicotine poisoning can paralyze the color-sense, so may we conceive the development of a secretion in the body which has a similar action." But the general rule is that women do not suffer from color-blindness, though they may have color-blind sons. It seems that in a woman there is a positive factor which counteracts the color-blindness factor, though that is present, and the counteracting factor is probably the femaleness factor itself.

Such a survey of the "Methods and Scope of Genetics" clearly shows that this new science has a bearing on the problem of evolution, and in the final paragraphs of this remarkable lecture the importance of Bateson's work and that of his school for the science of life in general is asserted moderately but convincingly:

The results of genetic research so novel as to require time for interpretation

"The facts of heredity and variation are the materials out of which all theories of evolution are constructed. At last by genetic methods we are beginning to obtain such facts of unimpeachable quality, and free from the flaws that were inevitable in older collections. From a survey of these materials we see something of the changes which will have to be made in the orthodox edifice to admit of their incorporation, but he must be rash indeed who would now attempt a comprehensive reconstruction. The results of genetic research are so bewilderingly novel, that we need time and an exhaustive study of their inter-relations before we can hope to see them in proper value and perspective. . . . We cannot think yet of interpreting these complex phenomena in terms of a common plan. All that we know is that there is now open for our scrutiny a world of varied, orderly, and specific physiological wonders into which we have as yet only peeped. To lay down positive propositions as to the origin and inter-relation of species in general now would be a task as fruitless as that of a chemist must have been who had tried to state the relationship of the elements before their properties had been investigated."

Evolution not a problem at large, but one of critical analysis

"For the first time *variation* and *reversion* have a concrete, palpable meaning. Hitherto they have stood by in all evolutionary debates, convenient genii, ready to perform as little or as much as might be desired by the conjurer. That vaporous stage of their existence is over, and we see variation shaping itself as a definite, physiological element, the addition or omission of one or more definite elements; and reversion as that particular addition or subtraction which brings the total of the elements back to something it had been before in the history of the race."

"The time for discussion of evolution as a problem at large is closed. We face the problem now as one soluble by minute, critical analysis. Lord Acton, in his inaugural lecture, said that in the study of history we are at the beginning of the documentary age. No one will charge me with disrespect to the great name we commemorate this year if I apply those words to the history of evolution. Darwin it was who first showed us that the species have a history that can be read at all. If in the new reading of that history there be found departures from the text laid down in his first recension, it is not to his fearless spirit that they will bring dismay."

The organism a living mosaic, made up of a vast number of units

Such was the position of genetics as stated by its founder in 1908. Very great developments have occurred since then, by the use of the key and the methods provided by Mendel. We shall observe that, in one of the preceding quotations, Pro-

fessor Bateson excepts the case of what he calls "originating variations" — *i.e.*, actual novelties appearing for the first time in the history of the species. They remain the question of questions, and we must beware of supposing that Mendelism, or contemporary genetics, can solve it. Elsewhere we see what hope there is of contributing to its solution by specially devised experiments. Meanwhile, we have to deal with a theory, and a method, which gives us the key to the transmission, the combinations, the partings and recombinations of characters already existing.

Our present business is enormously to extend the range of facts which this key will enable us to ascertain. It gives us the idea of a living creature as a living mosaic, made up of a vast number of definite, characteristic units, which may be arranged and combined in many patterns. We have to analyze as many living creatures as possible, so as to define their mosaic constitution; and we see that the method of experimental breeding will reveal what the knife and the dissecting-table are quite inept for. Nothing but the genetic method could tell us that under the black coat of a mouse there is a chocolate coat, if the factor for blackness were not there to conceal it.

The genetic problem of the couplings and repulsions of the formative units

Only the genetic method can show us how the couplings and repulsions and complementary action of different factors affect the constitution and characteristics of living things. Only the genetic method gives us the key to all those forms of true variation which depend upon different shufflings and distributions of the factors in the germ-cells. Only the genetic method will enable us really to appreciate the influence of environment upon the development of the living creature, for until we know its natural possibilities we cannot estimate the action of nurture upon it.

Similarly, such terms as reversion, atavism, "throw-backs", "skipping a generation", and many besides, which have darkened counsel for decades, are being given a real meaning by genetics. We see that when two modern fancy pigeons are mated, and the offspring revert to the characteristics of the ancestral rock-pigeon, nothing more mysterious has happened than the coming together again of factors which were together in the ancestral form, but had been parted in the modern varieties. That is the simple and efficient explanation of true reversion. Other cases of so-called reversion, like feeble-mindedness in mankind, have been analyzed by the genetic method, and found to have nothing to do with reversion at all, but to be due to the absence of certain factors which condition the proper development of the nervous system, and which obey the laws of genetics in their transmission.

The unparalleled development of genetics as a branch of science

The rapidity of development in this branch of science is almost unparalleled, so efficient are a sound method and a sound theory. New researches are published every week, and the number of workers rapidly increases as men find how fertile this field is compared with such sterile stuff as the academic discussion of "natural selection". In other chapters of this group we have tried to state some of the well-established achievements of genetics at the present time. We shall find them substantial and suggestive; but we may as well warn ourselves against the supposition that any of these most recent elaborations of Mendelism throw a light upon the problem of problems, to which Professor Bateson can scarcely be said to have given adequate prominence in the lecture from which we have quoted. He indicates for us the essential discovery upon which his school is based, and qualifies his proposition by the words, "except in the rare cases of originating variations, the causation of which is still obscure". Let us duly note that these "originating variations", as Professor Bateson calls them, are the *sole material* of organic evolution, and that if he had described their causation as still utterly incomprehensible to mechanical science, instead of as merely "obscure", he would still more accurately have stated the limitations even of our newest knowledge.

THE DEFENSES OF PLANTS

How Plants that Live Near the Ground Ward Off Their Enemies with Poison, Dagger and Subterfuge

THE STRUGGLE WITH THE ANIMAL WORLD

IN the world of animate nature, so long as things are not interfered with by man, the general rule of life is that the race is to the swift, and might is right. All observations upon living creatures in a state of nature impress upon our minds forcibly the conclusion that the struggle for existence is a great reality, and none but the fittest survive. True, there are examples of plants and animals living more or less in dependence one upon the other, but even in such instances the benefit derived is usually for one of the individuals at the expense of the other. The broad, true statement remains — that plants and animals make no effort to help any but themselves. Altruism is the last product of human, ethical progress.

This being so, and granted that the evolution of plants and animals has proceeded through the ages on the lines of natural selection of the fittest to survive, it can be understood that, in the case of plants especially, what constitutes the fittest will frequently be some special means by which the plant can protect itself against attacks from all sides. Unfortunately — from the point of view of the plant — the flora constitutes the principal source of food supply for the animals, and the plants are therefore in a constant state of exposure to risk of life and danger of extermination. Other dangers, too, have to be faced besides that of consumption for food, but that in itself is such an important matter that for the moment we may confine our attention to it.

In an earlier chapter we paid some attention to the composition, from the chemical aspect, of plant structures, and we noticed among other things that the chlorophyll granules have a very similar composition to that of protoplasm; moreover, by their action, sugar and starch are manufactured, and the cells containing the green coloring matter also contain easily digested carbohydrates. Now, it just happens that these are precisely the kind of foodstuffs upon which the herbivorous animals subsist. Moreover, the herbivorous animals choose for their special food principally the chlorophyll-colored tissues. It is here we see the incessant battle for existence between the plant and animal worlds. The animal, presumably, merely acts upon the instinct of hunger, and has not the foresight to reason that the result of his indiscriminate feeding upon the green parts of plants will destroy their capacity for producing food afterwards. Man acts somewhat differently because, although he destroys very large quantities of green plants for purposes of his own, he usually leaves enough either of the individual plant or a sufficient number of individuals to replenish what he has taken for himself. But this protection meted out to plants by the reason of man is, after all, only extended to a very few species — namely, those which he himself requires for his own food or clothing, or for some other product in civilization. If nothing else existed to save the plants, man's foresight would be unavailing, because so few of them, comparatively, interest him in a sufficiently practical way. The plants are therefore thrown back upon themselves for protection, and hence there have been evolved a variety of structures and processes that may be summed up in the term "plant defenses".

When we consider the thoughtless methods but too frequently employed by man in cutting timber from mountain sides, leaving them bare and unproductive, we may even argue that man himself has ample opportunity to improve in his "intelligent" treatment of plants

Plant defenses are of very different kinds and degrees Some of them secure the plant absolutely from almost any sort of attack, while others merely enable them to attain relative immunity. Other arrangements are not merely protective to the plant itself, but are of deadly danger to those whose temerity prompts them to interfere with it.

How do animals know how to avoid injurious plants?

Among the more formidable plant defenses *poisons* at once occur to the mind; and it is interesting to note that most of the plant-poisons are found only in those portions of the plant where they are necessary for protection. That is to say, plant-poisons occur chiefly in the leaves, the flowers and the fruits. Another point to be kept in mind is that the different poisons secreted by the plant do not all act to the same extent upon all animals. For instance, the leaves of the common poison ivy (*Rhus Toxicodendron*) are very poisonous to our touch, and yet these very same leaves are the food upon which certain insects flourish.

So here we have the curious case of a plant protected against external enemies by its leaves containing a very deadly alkaloid, while, at the same time, the plant can supply small parts of itself for food to a tiny insect without being entirely sacrificed. The insect merely eats a few holes in the leaves; it does not destroy the entire plant.

It is very difficult to imagine how animals become possessed of the knowledge which enables them to avoid certain poisonous plants. We say that it is in virtue of their inherited instinct, but how that instinct became evolved in these definite directions is not quite so easy to demonstrate. This, however, is not the place to discuss that topic.

In some cases poisonous plants have quite a distinct smell, and we can understand how they may be readily avoided For instance, the thorn-apple, the common henbane, and the water hemlock have leaves the odor of which is distinctly disagreeable. But in quite a number of other cases no smell is noticeable to man until the leaf is bruised, yet these plants are just as carefully avoided by the animals of the field as is the more obviously dangerous group. In this last category may be placed the poison ivy and the hellebore. None of these is ever eaten by wild animals such as rabbits and deer so far as we know and all seem to be carefully avoided by the domesticated animals of the farm.

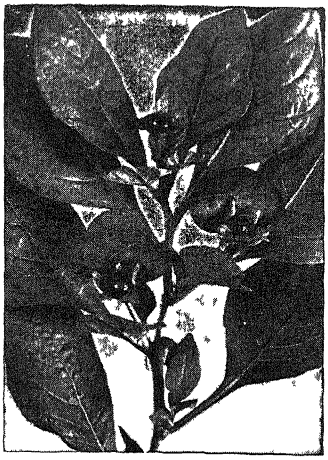
These plants, as we have said, have no perceptible odor — to us, at least — but it is, of course, possible that the more delicate sense of smell in the lower animals is sufficient to warn them of the danger. A further interesting point is that there are quite a number of plants not poisonous to man, but most scrupulously avoided by the herbivorous animals. In this list may be placed a number of mosses and ferns. Since these are so carefully avoided, the presumption may be that they would be injurious to the animals if partaken of. So that among the first of the defenses of plants against the attacks of animals must be the possession of poisonous qualities.

The indisposition of animals for feeding on plants impregnated with salts

Many plants have leaves so impregnated with salts of one sort or another, or mineral matter that they are either distasteful to animals or extremely indigestible. In the stems of the horse-tails, the leaves of the rhododendrons and in many of the evergreens found on our hills there is such a strong deposit of silica that they are not tempting morsels of food. The same is true of the plants composing much of the flora of the Australian bush.

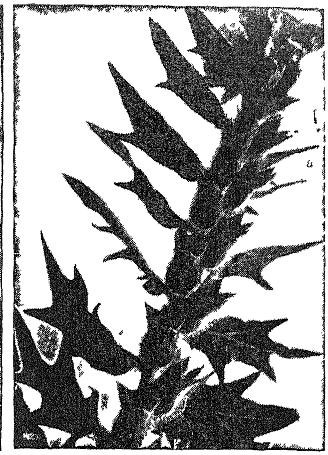
One would not imagine at first sight that the presence of water would have the protective power in connection with plants, but there is one connection, at least, in which water is a protection. Grazing animals do

PLANTS POISONOUS TO ANIMALS



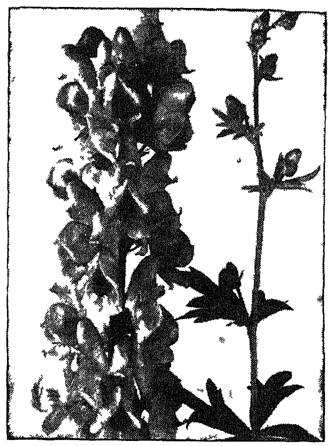
DEADLY NIGHTSHADE

THORNAPPLE



HENBANE

BARBERRY



MONK'S-HOOD

HORSETAIL

FENNEL

HELLEBORE

RHODODENDRON

not care to feed upon plants on whose leaves drops of water or dew are actually present. In response to this example of the immunity conferred upon such plants, some have developed quite a special capacity for retaining water in the form of dew. Among such plants are possibly the teasel or the compass plant whose leaves are so shaped that both rainwater and dew are retained at the bottom of the leaves in a little cup long after evaporation has dried the leaves of other plants in the immediate vicinity.

The many forms of prickle evolved as a defense

We next may turn attention to plant defenses in the form of weapons of armor, so to speak, structures exhibiting a distinctly threatening appearance, as if they said quite plainly: "Let him touch who dares." In this group we have the array of spines, prickles and thorns characteristic of so many plants. The distinction between these several defenses is that the spine is composed of actual wood, terminating in a sharp point; the prickle, on the other hand, is merely an epidermic structure, and contains no wood, though it ends in a point that is always strong enough to produce injury. Now, although all parts of a plant may possibly be more or less protected by spines or prickles, it will be found that they are especially arranged to protect the green leaves. If not actually on the leaves themselves, they are on those parts of the plant with which any animal attempting to injure the leaf would come in contact. The detailed position and size of these various protective structures evidently depend upon the kind of animals whose attacks are most to be feared, and the way in which the attack is likely to be delivered. So we find that the huge floating leaves of the *Victoria regia* are only protected on the under surface and at the margin, because only at these points are they liable to attack. Other plants are well protected during their infancy, so to speak, that being the time when they are most susceptible to danger. Once they reach such a height as to be beyond the reach of the mouth of the grazing animal, the thorns may disappear.

The arrangement hinted at above would show that some plants restrict their protective weapons actually to the site of danger, while others distribute their weapons in such a way that one part of the plant protects another, or the whole plant. Some, of course, such as some of the hawthorns, are so spiny as to have a distinctly formidable appearance.

Leaves of certain plants may have a number of little, sharp points projecting from the network; others may carry their armory at the margin, and these different structures, most of which are strengthened with silica, take the form of either prickles or hairs or bristles.

The leaf itself may be in the form of a needle, in which case it is termed *acicular*. It is an interesting point to note in passing that not only are such leaves very similar to needles in appearance, but in such parts of the world as are destitute of more perfect implements they are actually used by natives as needles. Plants with leaves of this type are particularly characteristic of dry, arid wastes and deserts, where, owing to the extreme paucity of vegetation, the green-leaf plants are subject to the attacks of animals. The highlands of Mexico are specially prolific in plants whose leaves terminate in a prominent thorn. These thorns are capable of inflicting extremely serious injuries upon any animal coming in contact with them. Other forms, like that of the aloe, occur in South Africa.

Another kind of defense is seen in the thistle, and plants of a similar nature. In them the leaves are all split up more or less, and have margins and ends with a very serviceable protection of prickles. Plants of this kind occur in widely spread areas. The result of the splitting up of the leaf is that there is not a great deal of green tissue left.

Arising from the actual surface of the leaf itself, as opposed to its point, we have the weapons in the shape of bristles, or barbs, whose points are generally very hard, from the presence of silica. A leaf the margin of which is protected in this way may be aptly compared to the edge of a saw with its teeth; and not only so, but it may actually be used in a precisely analogous way.

PLANTS WITH WEAPONS TO WARD OFF FOES


SEA-HOLLY


SOW-THISTLE

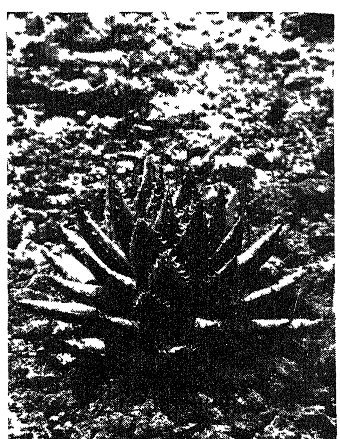

FURZE OR GORSE

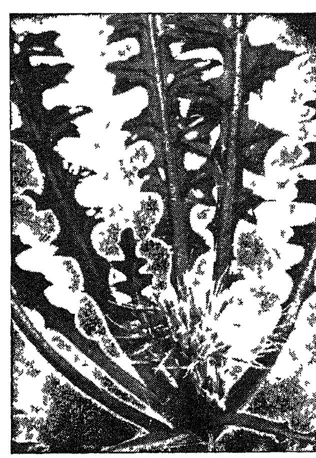

HAWTHORN


COLLETIA


SPINY OPUNTIA


BERBERIS


ALOE

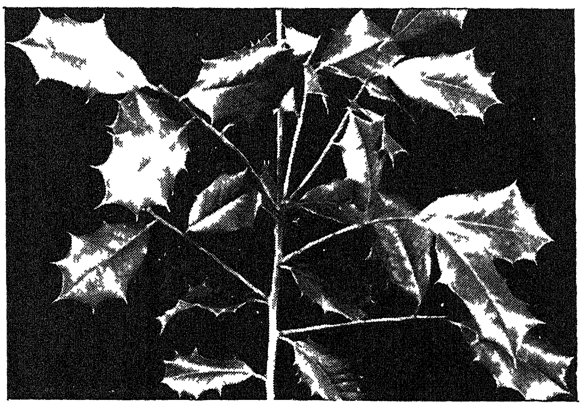

DWARF THISTLE

One can easily imagine how such forms of green leaves would be distinctly distasteful to grazing animals, whose lips and tongues would readily be lacerated by such weapons. Cut-grass, Leerzia and other grasses may show blades so impregnated in this manner with silica as to be capable of inflicting very serious wounds if touched.

Everyone must have had experience of the annoying little weapons possessed by many leaves in the form of sharp-pointed barbs that stick into the skin when the hand is brought into contact with the leaf. A variety of this kind of protection is seen to perfection in our own common indigenous nettle. The weapon here takes the form of a stinging hair composed of one large cell, which readily breaks off and leaves a portion of itself attached. A very slight contact is sufficient to break such a hair, and the fracture leaves behind it an extremely sharp-pointed portion, from which exudes an irritating substance of the nature of formic acid, and this is injected into the skin of the animal or person handling the leaf. The process is very similar to the arrangement of a hypodermic syringe. Considerable inflammation may be caused in the skin as the result of breaking off a number of hairs in a small area and the injection of their contents.

Everyone is familiar with the fact that if the nettle be handled in a certain manner these unpleasant effects may be avoided. It is possible to stroke a nettle with one's hand without being stung. For one thing, the lower part of the plant has no stinging hairs upon it. They are restricted to the foliage leaves. The hairs themselves are distinctly elastic, and can be pressed down so as to lie in close contact with the surface of the leaf. If, therefore, one grasps the nettle from below, and passes the hand upwards so as to press down the hairs on to the leaf, the hand will glide over them without causing any break in the hairs, and therefore without sustaining a wound. But, on the other hand, if the hand comes down on the leaf from above, the slightest touch breaks off the points of a number of the hairs, which pour out their poisonous contents. Here we have an excellent protective arrangement, therefore, against the depredations of grazing animals.

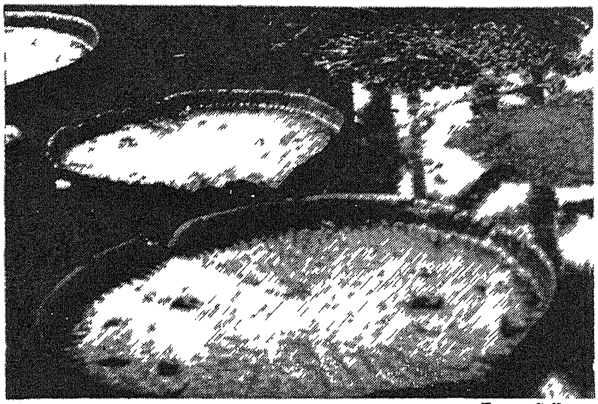
Thus far, then, we have seen that plant defenses may be in the nature of more or less offensive smells, which create a distaste in the animal for whom otherwise they might form food The dog-fennel and the hound's tongue are plants whose smell is evidently much disliked by ordinary grazing animals Secondly, we have noted that there may be contained in the leaf of a plant as well as possibly in some other parts of it, some extremely poisonous principle, generally in the nature of an alkaloid, as we get it in the water hemlock and the tobacco plant, and here, too, there is sometimes an odor associated with the plant which warns the animal of its nature, though sometimes the plant is odorless. Further, a great many plants have an extremely bitter, sour or acrid taste, sufficient to keep animals from troubling them. The leaves and shoots of the horse-chestnut and the maple are of this nature, and are avoided even by insects.



THE SMOOTH AND GLOSSY LEAVES OF THE HOLLY

Not only the leaves, however, are thus protected, because when one considers plants such as the potato, the peppers, mustard and horseradish one sees at once that different parts of the plant, or, indeed, almost all of it, may be distasteful. In certain plants smell and taste combine to produce their effect, and this is probably the case in many of the bulbs, like the onion.

Then we have seen that plants in arid and desert places are principally protected by the presence of extraordinary developments in the nature of thorns or cutting leaves. Also we have noted that a large number of our own indigenous plants are provided with thorns (excellently seen in the hawthorn), or others may have pointed, barbed, stinging hairs. A still further protection is conferred upon such plants as have hard, flinty stems, or very silicious leaves, both of which are indigestible.



Ewing Galloway

Water is the chief defense of this Victoria Regia.

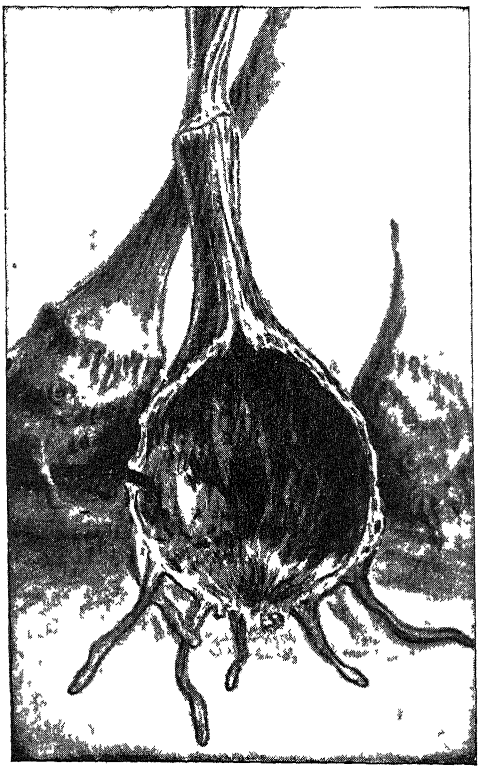
Plant defense, however, is not entirely a question of the provision of actual weapons. The plant is still not quite at the end of its resources, and may even turn to subterfuge, as it were, to protect itself. Thus we have very curious examples of what is termed *mimicry* in plants, the evident object being to suggest such a striking resemblance to something else as will cause the imitator to have his identity mistaken. Perhaps the best-known example of this process is that of the common dead-nettle. It takes this name from the fact that in general appearance it looks extremely like the common stinging nettle, though, as a matter of fact, it is quite devoid of such unpleasant properties. There are plants in South Africa which look like pebbles, while others are colored to resemble the earth.

THE STINGING NETTLE AND ITS MIMIC, THE RED DEAD-NETTLE

More peculiar still are the arrangements for self-protection in what are called the ant-plants, offering special inducements, as it were, to the ants to establish themselves upon these plants, or, rather, trees. True, some ants live upon vegetable food, but the great majority are animal-eaters, and destroy large numbers of insects. This has been turned to practical account by orange-growers in China, who deposit ant-nests in the trees, and construct bamboo bridges from one tree to another in order to allow the ants to pass.

A striking arrangement of this sort is to be found in an acacia, which provides special food for the ants at the end of its leaflets. The ants living on this material protect the leaves from any further attack Indeed, the number of plants with some sort of arrangement of this sort in order to attract ants, and thereby incidentally to repel other insects, is extraordinarily large This kind of relationship between a plant and an animal or a similar relationship between two or more plants or two or more animals where there is mutual benefit is termed *symbiosis* A plant living in this way with ants is said to live symbiotically with the ants, the plant providing a lodging and nourishment, and the fierce little ants providing a standing army against caterpillars, beetles and snails. The actual protection may be carried out by the

ants hurling their excretion of formic acid against the unwelcome visitors. Sometimes ants might have a sort of symbiotic relationship with plant lice and destroy the plants through attempting to maintain a too large population of lice on a given plant. The corn-root louse, for example, is cared for by an ant which lays bare the roots of corn and other grasses and places the lice on the exposed surface This helps the lice but hurts the corn.



A PSEUDO BULB OF AN ORCHID WITH AN ANT COLONY

The gardener wishing to protect a plant from the various smaller enemies of the animate world will sometimes surround his plant with water, standing the pot containing the plant in another containing the water, and so preventing the access of any insects that are not prepared to fly or to swim. Now, this isolation by means of surrounding water is, of course, found in the case of many water-plants, such as the water-lilies, and innumerable others, whose situation confers upon them an almost complete immunity from dangerous attack The visitors that arrive in their search for nectar and pollen serve more frequently the useful purpose of fertilization, while the injurious snails and insects, such as the ants, etc., are effectively warded off The same principle — though, of course, on a much smaller scale — is to be observed in plants which allow a slight portion of water to accumulate at the base of their leaves, as was suggested in the compass plant and teasel.

More common than even this last scheme is a mode of defense specially provided for the benefit of the flowers. We refer to the presence of extremely sticky secretions. Sometimes this secretion, which is excreted by the plant tissue, lies upon the surface, and entirely precludes insects from crawling over it. The sticky excretion often comes simply from the epidermis, and in other cases from special glands or hairs. The most common position for the protection of the flower is on the flower-stalk, or else the principal stem. A common example is to be found in the catch-fly, which takes its name from this very property. The protection derived from sticky secretions sometimes extends not merely to the flower, but to the whole foliage, as in certain of the primulas and saxifrages, on whose leaves the dead bodies of insects are frequently found adherent.

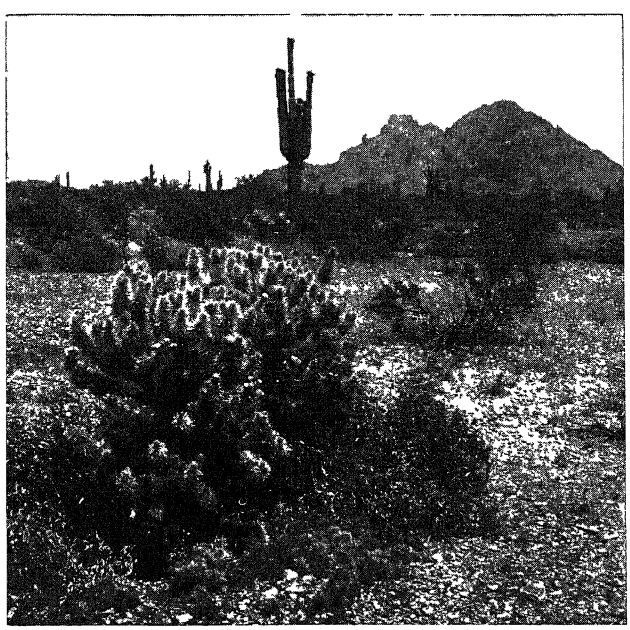
Then, also, it must be remembered that the wax-like covering, present in so many flowering parts, obviously is a means of protection to the flower from the entrance of insects. This, at any rate, is one part of its function. It is interesting to note, in passing, how varied plant defenses are to meet the attacking forces. Thus, a waxy exudate is no protection against a snail, for it will pass over it without any trouble. On the other hand, it is perfectly effective in the case of the hard-bodied little insects. They find in it an insuperable barrier.

When we come to consider the structure, nature and function of the flower itself, we shall have to refer again to this question of defense in connection with special parts of a flower. It will be sufficient to say here that most of the plant defenses, produced as protections against the winged insects,

are situated inside the flower, and are in the form of hair-like structures, arranged in a number of different ways. Then, again, the actual arrangement of the flower structure itself, especially as it affects the hiding and protection of the nectar is often extremely ingenious


THE CATCH-FLY AND ITS VICTIMS

Lastly, we may refer to the mechanical arrangements devised by plants to protect their stems and leaves against insects which would creep up them from the earth. One of the most ingenious of these arrangements is that occurring in some of the balsams, in which the sweet exudate secreted by the leaves, or in their vicinity, obviously protects the nectar of the flower, this flower-nectar being required to attract pollinating agents. There is a special gland developed from the stipule at the base of the leaf, which secretes the sweet exudate and attracts insects on their path upwards. They come in contact with a drop of sweet exudate at the base of every leaf, sweet exudate as good as the nectar found in the flower, and closer at hand. Ants, therefore, in search of nectar, go so far, and no farther. In the absence of such provision, they would, of course, search out the nectar within the flower itself, and would thereby interfere with the visits of those winged insects whose arrival is necessary in order that pollination may be effected and the plant's spread extended.


THE WELL-DEFENDED PRICKLY CACTUS OF THE ARIZONA DESERT

Then it must also be remembered that all the many and varied devices to be found in plants, by means of which insects are attracted and guided to different portions where they find food provided for them; all the various arrangements of petals, which assist in cross-pollination; all the manifold provision for the dispersion of seeds and fruits; all the protective structures of seeds and fruits, as well as an infinite number of other considerations, might very well be regarded as coming under the general heading of plant defenses. Defense is always such a varied problem, involving not only the repelling of enemies but the attraction of friends, that it is not at all surprising that our plants should show and use not only these many types discussed but many others as well, often of the most amazing ingenuity.

A TOOTHY INHABITANT OF THE FAR NORTH

American Museum of Natural History

An adult walrus taking his ease The walrus is related to the seals, it is a heavily built animal, which reaches a length of thirteen feet. Its formidable tusks are sometimes almost three feet long

FIN-FOOTED CARNIVORES

Intelligent and Affectionate Creatures Hunted with Ruthless Cruelty between Land and Sea to Decorate a Lady

BLIND EXTINCTION OF ANIMAL RACES

THE limbs of animals possessing backbones are derived from the fins of their fish-like ancestors. The seals are fin-footed. Are they, then, to be reckoned highly specialized fishes? It is hardly a conclusive answer that the true seal, a prince of the waters, has, when young, to be taught to swim, and cannot, therefore, be descended from a fish. The genealogy of the seals must be sought in other directions than this, though the fact, taken in conjunction with others, has a decided value. It is easier to convince the skeptic of the true mammalian character of the seals than of the whales. The seals make their living in the waters, it is true, but they are simply flesh-eating, water-dwelling mammals.

Scientifically they are classed as a suborder of the true carnivora, and, with the latter, constitute the fourth mammalian order. We can trace them as far back as the Miocene period, but no further; and, although they present certain resemblances to living animals, as to the bear, and, more particularly, to the sea-otter, the resemblance is purely superficial, and has no true significance.

The seals are directly descended, it is thought, from primitive carnivores, the creodonts, which were swept out of existence in the stress of competition with the animals of more highly organized brain from which the true carnivora developed. The ancestors of the seals and walruses were driven into the waters. They left the land as four-footed animals, possessing the same number and arrangement of bones with other carnivores.

Their limbs have undergone a strange transformation, with the result that, although the five digits remain to each foot, all four of the latter have become modified into paddles, or fins, still serviceable for progress, of a shuffling sort, on land. We use the term "fin" for lack of a better, but, except in the true seals, which have the most degenerate of hind limbs, the fin-like function of the feet is more apparent than real. The limbs are inclosed up to the wrists and ankles by the skin of the body, but, whereas the true seals have the hind feet thrust straight out and backward, the eared seals can, by arching the body, draw the hind feet under them, and employ them for land travel. The true seal, on the other hand, when it leaves the water, brings the under part of the feet together, like the hands of a man about to take a header into the water.

But, it may reasonably be asked, why, when the whole build of the seals and walruses is so remarkably adapted to an aquatic existence, should there be this retention of limbs for land travel? The reason is that the members of all three families are born land animals. Man walks before he can run; the pinnipeds walk, so to speak, before they can swim. The presumption is that when the ancestors of the fin-foots first took to the water they were as agile on terra firma as most other carnivores. But in the unending and sanguinary struggle for a living they had brain enough to discover that the path of least resistance lay in the waters, and they naturally betook themselves to that path.

They must have been animals of a high order of intelligence, for it is to be supposed that their life in the sea would not so highly tax their mental capacity as to have necessitated the really fine brain which they now possess, and which makes them highly educable. Strange as it may seem, these creatures, whose way lies in the vasty deep, are, under favorable circumstances, more easily domesticated than almost any other animal, and show remarkable affection and intelligence. Perhaps it is because the captive seal is more under observation than the free animal, but it always seems as though the intelligence of these animals finds its highest expression when in association with man, and not when at liberty.

The lack of sufficient adaptability in seals to escape disease

For all their wonderful brain, the pinnipeds when at large display the greatest stupidity at times, and, even when not pursued by man, fall victims in thousands to their blind persistence in seeking sandy shores as breeding places, where the young become infested with a species of roundworm (*Uncinaria*). The eggs of this parasite lie dormant throughout the winter in the sand of the breeding places of the fur seal. When the seals return from their winter migration, the eggs become attached to the fur of the adult seals, and pass from the body of the female into the interior of the infant seal, where they develop and multiply, at the cost of the young seal's life, feeding upon the blood of the animal until the latter dies of anæmia.

This parasite cannot exist on rocky rookeries, but the intelligence of the seal falls short of reasoning power enough to grasp the danger to its kind from sandy nurseries, and the lives of thousands of young seals yearly pay forfeit. An animal whose feelings are sensitive enough to induce it to shed actual tears of woe when ill befalls its young, which happens in the case of the seals, might perhaps be expected by this time to have learned to avoid these death-traps. But then we might also expect seals to avoid bringing forth their young upon land at all, and so escape the hideous slaughter inflicted by man. It is quite likely, however, that the land parasite would be equal to the task of changing its habitat too, as has the flea that once flew, and continued residence in the sea would not bring immunity from man, as we shall presently see. If we could give the seals a few million years free from man-persecution, and with no enemies worse than parasites and such animal foes as the polar bear on land, the shark and the grampus and other deep-sea terrors in the waters, they would probably make themselves masters of a wiser way in life. But that is beyond the best of us.

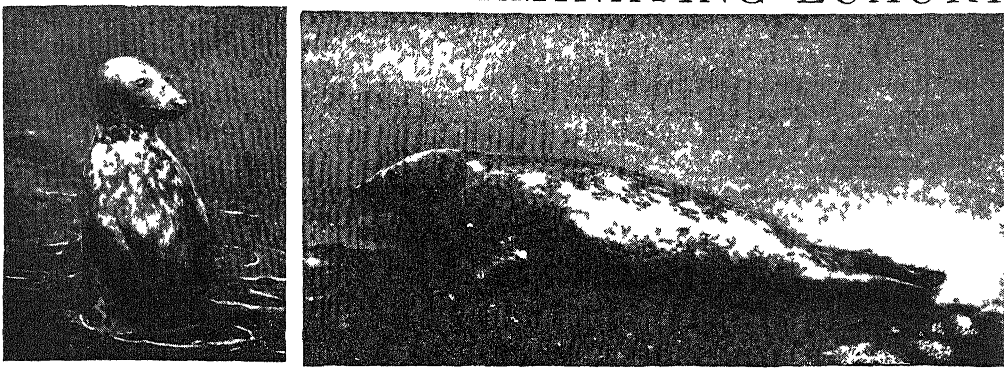
Our present suborder embraces three families. The first is the eared seals, and is made up of the sea-lions and sea-bears. The next consists only of the walrus, while the third is divided into nine genera, the last being the mighty sea-elephant. The first family, then, is that of the sea-lions and sea-bears, of which there is one genus, comprising nine species. There is no difficulty in distinguishing members of this genus from the true seals. They have distinct external ears, the true seals have not. The eared seals have a well-defined neck, and their hind feet turn forward, not outward in the manner of the true seals.

The curious diversity of habits in the sea-lions and the true seals

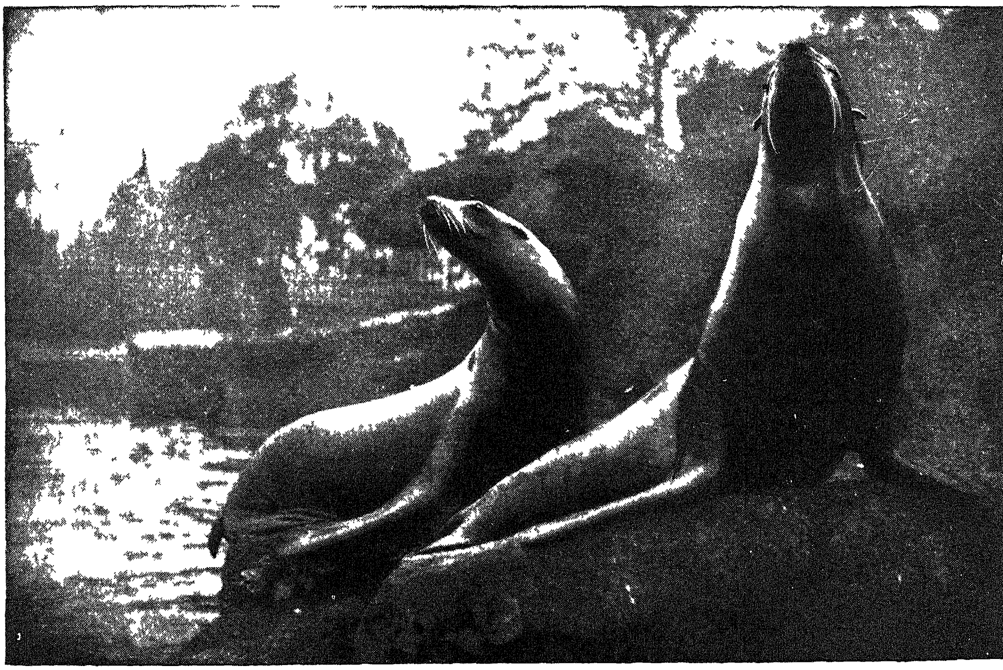
The sea-lion has a coat of close hair, and is sometimes termed a hair seal; the sea-bear has a close, woolly undercoat beneath the long hair, and this is the fur seal. The long hairs are removed by the furrier, and the beautiful undergrowth remains as the fur of commerce. Sea-bears and sea-lions frequent the same shores for breeding, though not seeking the same sites; and the genus is widely represented in both the northern and southern hemispheres, though missing from the North Atlantic.

Sea-lions, using the term to describe the whole of the eared seals, differ in habit from the true seals in that they pass a good deal of their time on land, and make regularly for fixed breeding places, where each male becomes, or seeks to become, the lord of a flourishing harem.

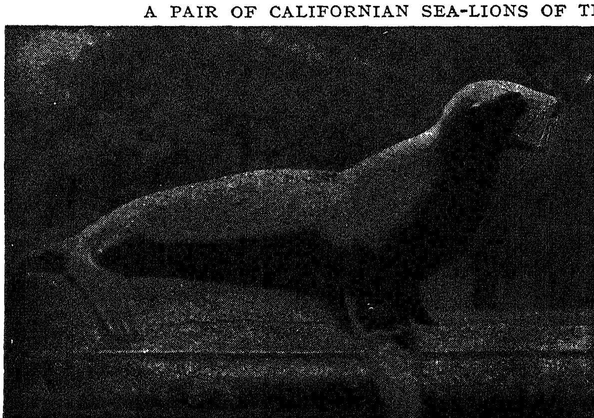
VICTIMS OF EXTERMINATING LUXURY



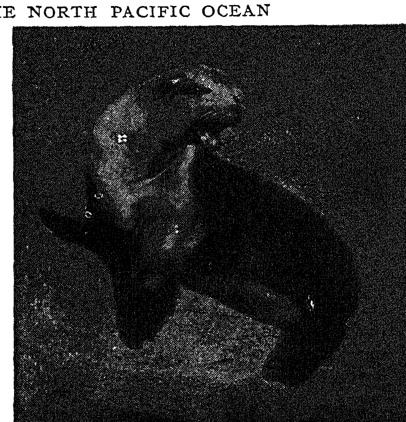
THE NORTH ATLANTIC GRAY SEAL ON THE WATER AND ON A BANK



A PAIR OF CALIFORNIAN SEA-LIONS OF THE NORTH PACIFIC OCEAN



A SOUTH AFRICAN SEA-LION



A YOUNG SEA-LION

The sanguinary battles of the sea-lions in the mating season

The true seals, on the other hand, do not undertake these long migrations, but rear their young upon land, or upon ice-floes near which they may happen to be. Moreover, they are for the most part strictly monogamous. A "rookery" of sea-lions has often been described, but the picture is strange enough to warrant a brief recapitulation.

The bulls arrive first at the breeding grounds, toward the close of May or the beginning of June. The females follow about three weeks later. Each of the strongest bulls takes his own station, some ten feet square, and to this he seeks to cajole or bully the fairest of the opposite sex. But as many beating hearts may be set upon one and the same acquisition, the right to possession can be decided only by sanguinary combat. The males nearest the sea make their choice there, and haul their loves high and dry to land. But as another female appears at the water's edge, the gallant male goes to her assistance too, and in his absence a second bull steals the unguarded cow, only perhaps to lose her to another rival. And this sort of thing continuing, the female, first settled upon a water-line station, may find herself finally deposited in a seraglio fully 150 feet inland, having in the meantime been hauled from station to station by upward of a dozen rival males. Each transference causes a battle, and the life of the sturdy old bulls down upon the coast is one long round of engagements until the last female has come ashore.

The fighting is done with the mouth. The rivals spar and feint with averted heads, then thrust out their long necks and fasten on with their powerful teeth. Once the jaws close they do not reopen; the flesh must tear. Gouged eyes, flippers torn to ribbons, and hide and blubber sorely gashed mark the price which the victor has paid for his many victories. There are always more males than harems. The unsuccessful are driven inland, among them some who have set up housekeeping and then been ejected after battle.

Soon after their arrival, the females give birth each to one young one, or, rarely, two. Then they are at liberty temporarily to revisit the sea in quest of food. They do not desert their little ones, but return to feed them, and it is a well-established fact that the mother can distinguish the cry of her own pup or calf from a host of others and go unerringly to it. It is while the mother is on these feeding expeditions that such cruel havoc has been wrought by seal-hunters, who slay the animals in the water. Of course, at such times only females are on the move. The males never leave land from their first arrival, but pass, it may be, four months on shore without food or drink. Here it should be mentioned, by the way, that the sea-lions do not drink, in the ordinary sense, but are content with such moisture as adheres to the fish that they eat. True seals do drink, occasionally. To return, however, to the matron in the midst of the sea.

The quest of the pelagic sealer is not confined merely to the breeding months proper; it extends over the period during which the seals are making their way to the breeding grounds, at a time, of course, when the females are about to bring forth their young. Those that then escape have to run the gauntlet whenever they go out to feed, and as the distance covered extends to between a hundred and two hundred miles the danger is considerable. Every female killed at such a time represents the loss of three seals — the mother, her young one on shore, and a further young one which should be born in the following summer. For, very soon after the birth of one little seal, the matron has expectations of a successor. Therein lies the mischief and much of the horror of the trade. For every female seal killed under such circumstances there is a pup seal left to die of slow starvation on shore, and there can be no possible doubt that the official estimate is well within the mark when it states that the ocean catch of 27,000 and odd skins in a recent year represented a loss to the herd of over 75,000 animals. It is from the slaughter of these seals at sea that the genus has been driven so far on the road to extermination.

But it has brought a wonderful thing to pass The nations most interested met and agreed upon protective measures to safeguard the fur seals. In 1912 the commercial catch was cut off for five years, and thereafter strictly controlled according to the terms of the agreement signed by Great Britain, Russia, Japan and the United States

This treaty regulating sealing recognized the fact that, of all the rookeries of the fur seals, only two remain of any real commercial account, and those are the Pribilof Islands, Alaska, belonging to the United States, and the Commander Islands, in the Behring Sea, belonging to Russia. Other ancient strongholds have been desolated, so much so that seal nurseries owned by Japan are not deemed even worthy of mention. It is sad that there should have to be this admission in an international treaty.

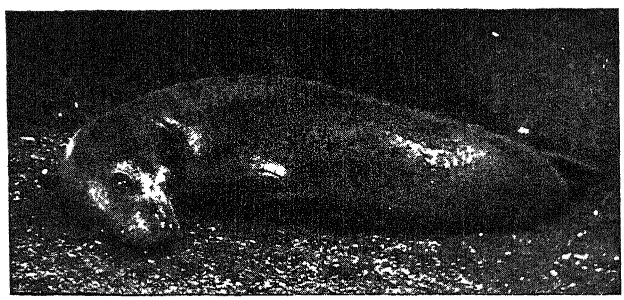
The second remarkable aspect of the compact is this: that four great Powers have had to confess that unless old methods are summarily inhibited, the fur seal will soon be as dead as the dodo. And to prevent this we have the extraordinary spectacle of two Powers buying off the other two. Russia and the United States say to Great Britain and Japan: "If you will cease catching seals in the sea and leave the business to us on land, we will repay you to the extent of 15 per cent of our catch." To that course the other two nations agreed, and the bargain came into effect in 1911. But, be it noted, this applies only to the fur seal, not to the true seal. Commercial prudence, not pity, has dictated the move.

Photo Ewing Galloway, N. Y.

A HERD OF FUR SEALS ON THE ROCKY COAST OF THE PRIBILOF ISLANDS, ALASKA

There is an enormous market for sealskins. The United States has made a double profit on them, first by their sale, secondly by import duties after they have

been returned from dressing in England. We paid, approximately, $7,000,000 for the Alaskan territory, and for twenty years received from sealskins alone more than twice that amount. But in those days the seal herd numbered 2,500,000 with vast potentialities of increase. Insensate slaughter on sea and land — 80 per cent, it is computed, at sea — brought down that splendid herd, in less than thirty years, to 185,000 seals. Another year or two of unchecked slaughter would have seen the end of the genus of northern fur seals. And that is why this unusual international treaty was effected. Now the sealing is in American and Russian hands. The arrangement is that only the superfluous males will be killed, and those at the breeding places, when sex can be instantly determined before the lethal blow is struck. But the Powers ought to have gone a step beyond the dictates of mere commercial prudence; they should have spoken one word, at least, in pity.



THE MONK OR MEDITERRANEAN SEAL

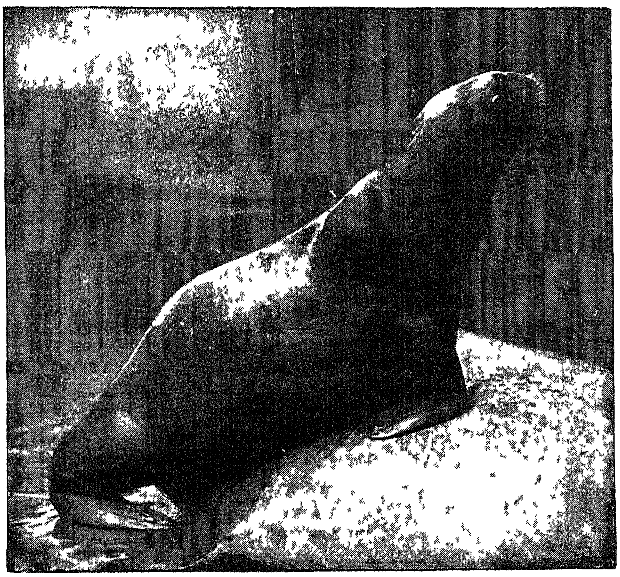
There is no more sickening chapter in the pages of commerce than that relating to seal-hunting. It is a sanguinary, brutal, disgusting business, and if the details were but known and realized it would make us all forever forswear sealskin. The hunters descend upon these lonely nurseries, head off the seals from the water, and drive them like sheep inland to the killing grounds. The wretched animals, all unfitted for land travel are driven over miles of rocky, broken track. Panting, struggling, foaming at the mouth, falling exhausted by the way, they are urged forward, and when at last they come to the appointed place they are made to pass between men armed with bludgeons. With such force are the seals struck that, according to an official publication, "the crystalline lenses of their eyes fly out from the orbital sockets like hailstones".

Equally shameful is the treatment of pregnant seals, which, out of coat themselves, and therefore useless, are killed in order that there may be obtained the fœtal sealskin, which is more prized for its softness and delicacy than all other forms. Surely, if facts such as these were driven home to the public mind, the sealskin would no longer be the hall-mark of affluence and prosperity. But it is these things which make us wish that the treaty included one word of pity for the animal itself. Commerce, not humanity, speaks in the epoch-marking agreement There is nothing new in that, of course; more than a century ago the Russian Fur Company threw into the water at Unalaschka, their then chief fur-trading station, 700,000 skins, "in order not to glut the market".

Sandwiched between the eared seals and the true seals come the walruses, huge sea animals, larger even than the largest of the sea-lions, though these latter attain a length of 13 feet and a weight of 1300 pounds. It is in bulk rather than in length that the walrus exceeds the sea-lion, large specimens being estimated at as much as 3000 pounds. Like the eared seals, the walrus turns its hind feet under the body to assist it when on land, but its tusks constitute the feature by which even the tyro can immediately identify it. These tusks, which are of dense ivory, are produced from the upper jaw, and measure from 18 inches up to 32 inches. The habits of the walrus are less well understood than those of the seals; butchers, not nature students, are, as a rule, its human visitors. It is well known, however, that the tusks act mainly as weapons, and perhaps are employed in rooting among sediment and weeds for the small marine creatures which, with molluscs, form its diet. The teeth are few in number, and reduced to mere pegs, barely

clearing the surface of the gum. Restricted now to the coldest waters, the walrus at one time had a considerable range. Today it is one of the dying groups. Its icebound home is no sanctuary. Its blubber yields abundant oil, so the animal must die.

The walrus is quite harmless unless attacked, when a male will fiercely retaliate, and overturn the stoutest boat. Many cases are recorded of walruses acting in concert in these circumstances, after one of their number has been injured; and at such time they are foes much to be feared. They betray considerable solicitude for a wounded comrade, and hunters take advantage of this to slay all within reach; the animals that might escape unwounded remain to help the injured, and all fall victims to their persecutors.


A YOUNG AND TUSKLESS WALRUS

Hagenback, who has had fortunate experiences of young walruses in captivity, mentions an instance in which a certain sea captain, of whom he was in the habit of buying captured walruses, discovered on the coast of Northeast Land, 370 of these animals, all females. "Every one of them was slaughtered by five ships' crews." It would be interesting to know whether this incident has any connection with a crime against nature cited by Lieutenant-Colonel William Wood in an address delivered before the Commission of Conservation at Quebec: "Not so many years ago some whalers secured a lot of walrus hides and tusks by having a whole herd of walruses wiped out, in spite of the fact that these animals were at that very time known to be the only food available for a neighboring tribe of Eskimos. The Eskimos were starved to death, every soul among them, as the government explorers found out."

The earless, or true, seals, distinguished by characteristics which we have already considered, are a very varied group, divided into nine genera, including the mighty sea-elephant. Although they lack that extraordinary faculty of the sea-lion for balancing things on the end of the nose, they are remarkably educable and mentally alert. There seems little doubt that they have a genuine liking for music. Church bells, flinging their melody out from the cliffs over the seal's sea home, always draw these animals to the shore; while the sound of melody from ship or boat proves equally attractive. There is the suggestion that curiosity, not appreciation of harmonious sound, may account for this oft-noted phenomenon, and it is disappointing to learn that of all the animals experimented upon by musicians at the Zoo, the seals alone remained indifferent.

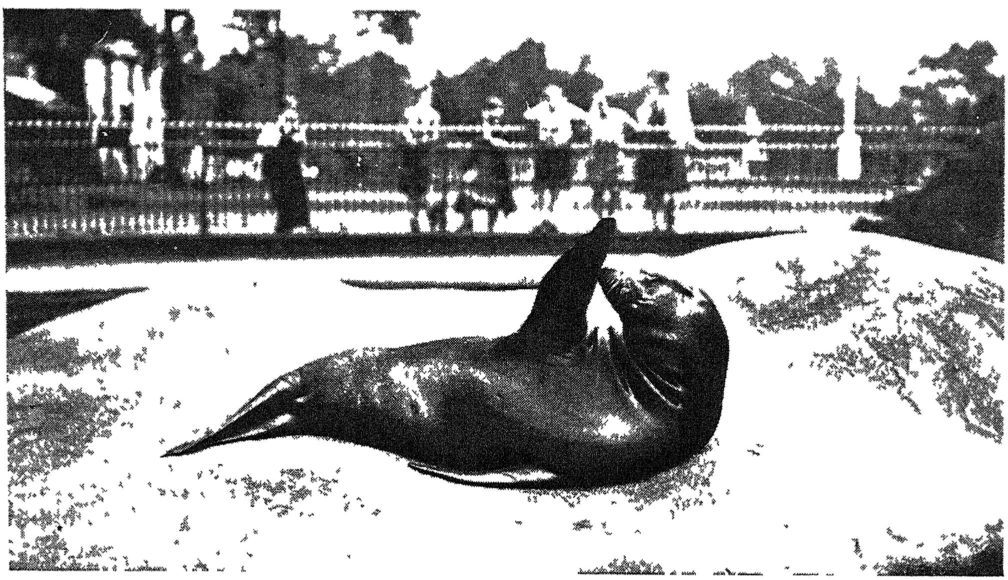
The true seals are to be found — in sadly diminishing numbers, it is true — in most seas, the majority favoring the northern hemisphere, where they produce their young, as a rule, on the ice. They ascend tidal rivers, but are mainly marine in habit, of course. But there is this remarkable fact about the distribution of the seal: that distinct species are found in the inland Caspian Sea, in the great Lake Aral, and in Lake Baikal, which, after the Caspian and Aral, is the largest body of inland water in Asia. The supposition is that the presence of seals in these waters indicates a prior connection with the sea.

But seals can travel on land, if necessary, — a short way in a long time. It is recorded that a gray seal traversed fully thirty miles of snow-covered land in Norway, the time taken, it is believed, being about a week. Whether they would have endurance enough to find their way from some other watercourse to the inland seas mentioned is, of course, another matter.

Many seals are destroyed on land by polar bears, and many in the waters by killer whales. But the shark is also an enemy of this animal. The common seal along our coasts is called the "harbor" or "leopard" seal. It is one of the smallest of the true seals, rarely exceeding a length of five or six feet, and is whitish in color, heavily spotted with gray. It sometimes finds its way into the Great Lakes or other inland bodies of water having a connection with the sea, but it is nowhere regarded with friendly interest by fishermen whose nets it frequently robs or even destroys in its pursuit of fish. It is found in both the Atlantic and Pacific as far south as North Carolina and Lower California though not abundant south of Maine and British Columbia. It is not as gregarious as other seals and, therefore, in no present danger of extermination.

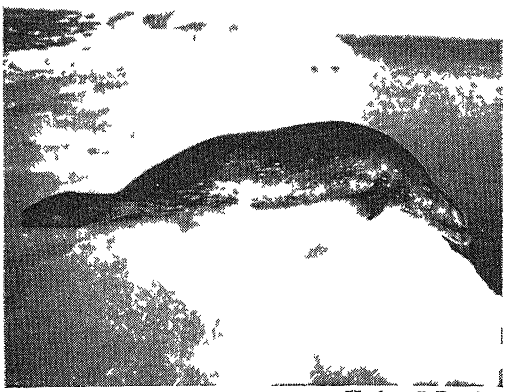
Because of lack of space we cannot mention here all the various genera of the true seals; but the sea elephant, or elephant seal, must be noted. This is indeed a prodigious beast, with a length of from to 20 to 22 feet, and a girth of from 15 to 16 feet, these dimensions relating to males only, for the females are considerably smaller. The enormous coating of blubber by which the animal is enveloped is a perfect protection against cold, for it has been found that the body of a sea elephant that has lain for twelve hours in the icy water of the Arctic fully retains its internal heat. Formerly to be found in enormous herds, sea elephants are now relatively few in number.

One species, the California sea elephant, was nearly exterminated in the early years of the twentieth century. Conservation practices in those days were decidedly sketchy, to say the least; the animals had been considered fair prey for years by whalers and sealers. Naturally there had been an indiscriminate slaughter of the helpless beasts; the few that remained made their final bid for life on the island of Guadelupe, off the coast of Lower California. Since there was no law, written or unwritten, to protect them, it seemed only a matter of time before



New York Zoological Society

A CALIFORNIA SEA LION BLISSFULLY SUNNING ITSELF

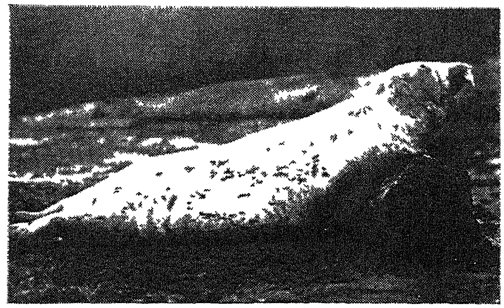


Herbert J. Pontine

A Weddell seal about to dive for its prey.

were so near to extinction. But the expedition was sent to Guadelupe nevertheless.

The members of the expedition, with true scientific zeal, photographed the animals as they lay on land, then killed them and sent the carcasses home to be preserved. At the same time a horde of whalers and sealers descended upon the island and began their own slaughter of the innocents. The sea elephants on Guadelupe, menaced by commercial killers and scientific killers, seemed doomed to destruction. Fortunately, however, some of the animals either managed to escape detection or else were not



U.S. Fish and Wildlife Service

The harbor seal frequents harbors and river mouths.

they would all be slaughtered by the rapacious hunters of whales and seals.

But this was not the only threat to their existence. A rich English collector, who had become interested in these huge animals, was appalled to learn that there was not a single adult specimen in any museum in the world. He determined, therefore, to send out an expedition to Guadelupe in order to obtain a number of specimens for museums before the animals should be utterly exterminated. He was hotly denounced by many naturalists and by animal lovers generally. They felt that it was all very well to provide specimens for our museums, but that it was not right to seek specimens of animals that

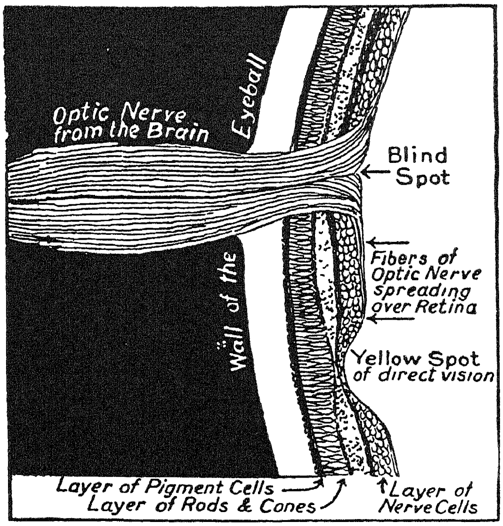
Australia News and Information Bureau

A fur seal that is found in Australian waters.

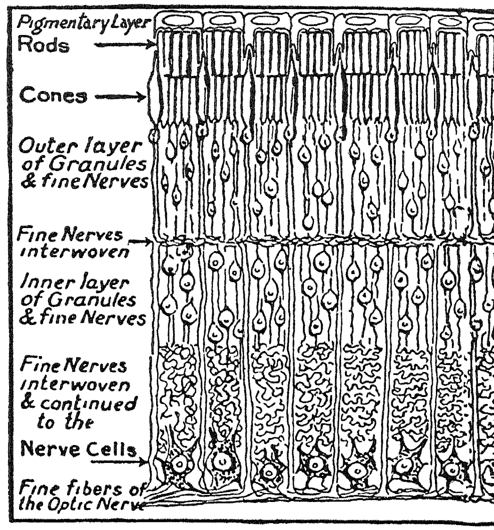
on the island when the slaughter took place. When Guadelupe was visited by an exploring party in 1919, a small herd of the enormous beasts was still holding its own.

These seals breed from February to June; during this period they are often to be found on the shore. Here they are sluggish and ungainly. They appear to be quite unaware that they have a deadly potential enemy in man; they show no signs of fear when humans approach them. When they are attacked, their attempts to escape are pathetically futile, since they move about with difficulty on land and quickly become exhausted. They are more truly in their element when swimming about in the sea; here their chief enemy is the killer whale.

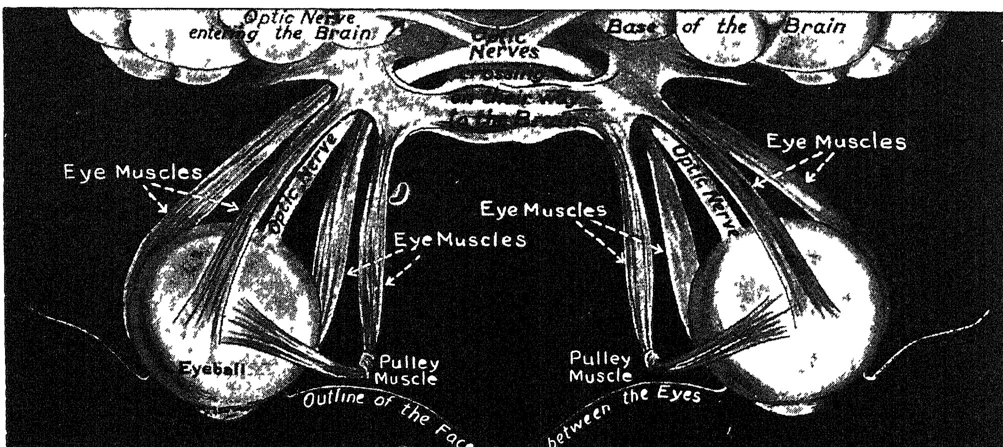
Another species of sea elephant makes its home in the vicinity of various islands in the Antarctic region; the big animals live on friendly terms with their neighbors, the penguins. The Antarctic sea elephants have a better chance to survive in the years to come than their northern cousins.



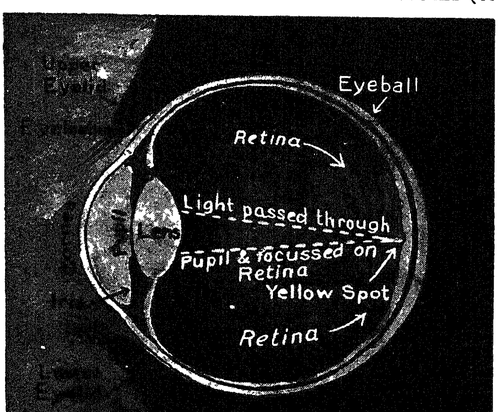
A SECTION OF THE EYEBALL THROUGH THE BLIND SPOT AND THE OPTIC NERVE



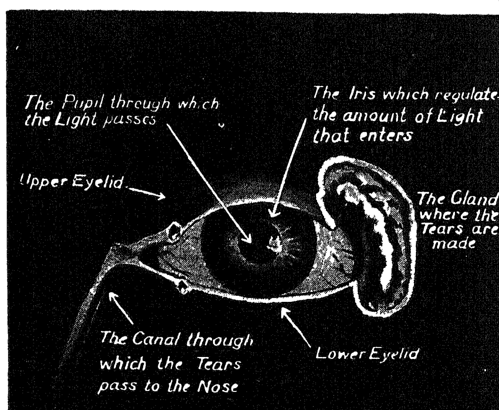
THE NERVE LAYERS AND RODS AND CONES THAT FORM THE RETINA — HIGHLY MAGNIFIED



HOW EACH EYE IS WORKED BY ITS 6 MUSCLES (ONLY 4 OF WHICH CAN BE SHOWN IN THIS DIAGRAM)



HOW THE LIGHT IS FOCUSED ON THE RETINA IN A PERFECT EYE



THE GLANDS AND DUCTS THAT CLEANSE THE EYEBALL OF THE LEFT EYE

THE EYE AND VISION

The Marvelous Mechanical Contrivances of the Eye for the Transmission of the Materials of Sight

HOW THE BRAIN SEES, RECALLS AND CREATES

THOUGH perhaps not the most ancient, vision is in many ways the most important of the senses, and particularly so for the psychologist, since vision illustrates most clearly and in the highest degree all the stages from simple sensation up to perception and artistic creation. The eye and the visual apparatus are themselves, of course, part of the body, but we have purposely left over their discussion, and that of the other organs of sense, in order to deal with them from the psychological point of view. We have already learned, however, that visual sensation has its "cortical representation" on the outer and inner surfaces of the occipital or hindmost lobe of the brain. Everything that we are about to study, though of high order and largely composed of nervous elements, is to be looked upon as subsidiary to the center of vision in the cortex cerebri. If that center be thrown out of action, blindness is the result. No vision is possible unless the cortical center, and the nerve fibers which run backwards straight through the substance of the brain until they reach it, are intact. We further note the fact that no *light* travels along these nerves or reaches the visual center, which remains in absolute darkness, though it alone sees. The waves of light which enter the eye are arrested at the curtain at the back of the eye, called the retina. Some of the light is reflected; the greater part is absorbed, and excites changes in the nervous elements of the retina, which in turn send nerve impulses through the optic nerve, or nerve of vision, which proceeds backwards towards the visual center. But no light travels even along the optic nerve.

The fact is that the particular kind of sensation we term vision is the peculiar property of the nerve-cells in this area of the cortex. If they exercise their function, we see Commonly and normally they are excited by light, but that is not essential; and perhaps the best proof of the fact that no light travels along the optic nerves and back to the brain when we see is that vision may be aroused by other means than light. Whatever agent excites action on the part of the cells in the visual area will produce in us sensations of vision These sensations may be thus aroused from without or from within. If the eyeball be struck, we are said to "see stars", and in this case the mere shock to the retina, and perhaps the sudden raising of the pressure within the eyeball, has excited impulses in the optic nerve, and we have sensations of vision without the action of light. Again, in dreams, in day-dreams, in reverie, or at any moment that we will, we have sensations of vision apart from the action of light. At such times as these, remembered things

> . . . flash upon that inward eye,
> Which is the bliss of solitude.

This "inward eye", as Wordsworth called it, is of course the visual area of the cortex; and there is no doubt that when we have visual memories, or visual hallucinations, it is this area of the cortex that is thrown into action. In dreams and nightmares vision usually plays a large part; and the explanation here is that the visual area, perhaps much overworked and excited in the normal way during the day, does not wholly rest, as it should, during sleep, but indulges in eccentric activities of its own,

the results of which are visual sensations on our part, though we are asleep, with closed eyes, in the darkness. This remarkable fact about the visual area is not peculiar to it, for the facts of the other centers of special sensation are the same. No sound reaches the nervous center of hearing, but only nerve impulses that run along the auditory nerve. That nerve may be excited by many agents other than sound, but, whatever excites it, the result is the sensation of hearing. And, further, the auditory center may be excited in dreams, in reverie, and in the processes of memory, so that we hear, more or less clearly, either sounds which we have never heard, or sounds which are recalled by the memory, though all the time we are in silence. Thus there is an inward ear, exactly as there is an inward eye. All sensations of vision and of hearing, whether excited by actual light or sound, or by abnormal disturbance of the optic or auditory nerves, or by subtler and deeper causes, have their seat in those cerebral centers; and any activity of those cerebral centers must result in vision or hearing respectively, and in nothing else. Our clear understanding of this "law of specific sensations" we owe to the great German pioneer Johannes Müller.

The formation of the retina from the protrusion of the primitive brain

But normally, of course, the visual center is thrown into action through an astonishing apparatus, which we briefly summarize as the eye. This apparatus is definitely of double origin, in part lofty and in part humble. When we study the deeper parts of it, we find many cells which are plainly nerve-cells, but in front of these the eye consists of cells of lower type.

The fact is that the front parts of the eye, such as the lens, were developed from an infolding of the ectoderm, the outer germ layer, in a very early stage of development; but the back parts of the eye, especially represented by the retina, are formed in man and the higher animals not from the body ectoderm but from the brain itself. Very early in development a protrusion appears from each side of the developing brain.

Now these two protrusions grow each one on what is practically an ever-lengthening stalk. As each advances, it meets the depression or infolding of the surface ectoderm, which has been passing inward to meet it. Thus the eye is formed, the retina being derived from the protrusion from the primitive brain, so that its nerve-cells are really brain-cells, as if a portion of the brain had come out of the cranium in order to see; and the stalk upon which this protrusion or bulb of nervous matter was borne becomes the optic nerve.

The bony protection of the eye from external dangers

Everything in front of the retina is therefore to be looked upon as subordinate in function to the nerve-cells of the retina, which are, so to speak, personally affected by the rays of light for which the front parts of the eye merely exist in order to transmit. This transmitting apparatus first claims our attention, but we need deal with it only briefly, as its functions are wholly mechanical, and the problems of psychology lie further back.

We note, then, the well-protected position of the eyeball within a bony chamber called the orbit, through the back of which the optic nerve passes outwards from the cranial cavity. The edges of the orbit are powerful and project very efficiently, so that a "black eye" commonly involves anything but the eye itself. The bony roof of the orbit is thin, however, and upon it rests part of the frontal lobe of the cerebrum. A carelessly handled umbrella may quite possibly penetrate this delicate roof of the orbit, and cause death by its action on the overlying brain. The eyebrows add further protection of a different kind, by diverting the perspiration from the forehead, so that it does not run into the eye. The eyelids are provided with hair for a similar purpose. When the eye is open the upper lid is held up by the pull of a tiny muscle attached to the back of it. When this muscle ceases to act, the upper lid drops of its own weight, and the eye is closed. But the entire eye is surrounded with a circular muscle, one of the muscles of the face, which is also attached to the lower

lid; and by the action of this muscle the eye can be actively closed and screwed up in certain states of emotion. Normally, however, the closing of the eye is simply the cessation of muscular action.

More remarkable is the regular and rhythmic fashion in which, during waking, the action of this muscle is momentarily arrested and then resumed. The arrest results in a momentary fall of the lid, which is then immediately raised, and this is what we call winking. It is a reflex action, dependent upon sensations of incipient dryness derived from the front of the eyeball, but it is scarcely an ordinary reflex action, though it is commonly so described, for the response here is, in fact, not an action, but inaction; not stimulation of a nerve, but inhibition of it. This is a very simple case, but a very significant one, for there is reason to suppose that a great many other acts, including even what can only be called acts of the will, are essentially inhibitions, as this is, and consist in forbidding what has hitherto been permitted.

The important part played in the eye by tears

The function of winking is clear. The front of the eye must be kept moist, with a thin, regular pellicle of fluid covering it both for clearness of vision and for the protection of the delicate surface. For this purpose there exists, under the upper eyelid, towards its outer side, a gland known as the lachrymal gland, which secretes from the blood a clear, saline fluid, practically what the physiologists call "normal saline" or "physiological salt solution", known in ordinary language as tears. The ducts of the lachrymal gland lead the tears to the under surface of the upper lid, and each time the lid is dropped it sweeps the front of the eye with a tear. How important this is for the eye is only known to the oculist who has to deal with cases where the secretion of the tears is interfered with. At the inner end of the lower lid there is a minute aperture through which the tears drain downwards into the nose. If this be blocked, or if the secretion of tears be over-abundant, they drop over the lower lid and run down the cheek.

The various structural parts of the front of the eye

The eyeball itself has a hard and dense outer coat, the "white of the eye", which is called the sclerotic coat. In the front of this there is inserted a circular transparent window, horny in consistence, which is hence termed the cornea. This cornea has a marked forward convexity, which is of much importance for vision. It should be neither too convex nor too little convex, and the degree of its convexity should be equal in all directions. Otherwise rays of light, say from the two limbs of a cross, will be unequally bent, and the condition called astigmatism will result. The cornea itself should be absolutely transparent and colorless. Inflammation of its surface, such as often attacks the uncared-for eyes of newborn infants, is often followed by opacity, and is the usual cause of the condition which is erroneously described as being "born blind". There are no blood-vessels in the cornea, of course, and it is nourished by lymph exuded from the walls of the capillaries which skirt it in the sclerotic coat of the eye.

Looking through the cornea we see a ring of color surrounding a circular black hole which is conspicuously variable in size. The black hole *is* a hole, leading into the dark chamber of the eye; but under certain conditions, as when we throw light into the eye by the ophthalmoscope, the dark hole becomes bright, and we see clearly the brilliant red back of the eye, by means of light reflected from it to our eyes. This black hole, or pupil, is surrounded by a muscular structure, called the iris, and the interval between pupil and iris behind, and the cornea in front, is known as the anterior chamber of the eye, and is filled with a transparent watery fluid known as the aqueous humor.

The exquisite graduation by the iris of light entering the eye

The color of the iris is not due to its muscular tissue, for in pink-eyed or albino animals or human beings the natural pink color of the blood in the muscle shows itself, but it is due to the presence

of pigment in certain pigment cells, upon the back of the iris in all but albinos, and upon the back and the front of the iris in brown, hazel and green eyes. The inheritance of the pigment upon the front of the iris — in the absence of which the eye is blue or clear grey — has lately been shown to follow the law of Mendel.

The iris is opaque, so that no light enters deeper into the eye except such as passes through the pupil. This quantity is exquisitely graduated by the iris, under the delicate nervous control of certain subordinate centers which are in connection with the retina, and so can signal to the iris according to the quantity of light which is falling upon the retina. Thus if we open the eyes before a mirror in any good light, we at once see the pupils contract, owing to the reflex stimulation of the iris by the light. When the eyes are closed this stimulation ceases, and the pupils dilate. This in itself means rest, of course, for the iris and the nerves which control it. Very few people have the wisdom, however, to appreciate the value of closing the eyes when there is nothing to see, though this simple act rests the whole visual apparatus, from the machinery which raises the upper lids back to the vision-center in the brain itself.

How concentration of light on the retina is secured

If the pupils of a friend be observed when the vision is directed from a distant object, such as a landscape seen through the window, to a near object, such as the glass of the window itself, we observe that the pupils contract in this case also, just as when more light is thrown into the eye. This is a beautiful adaptation for the purposes of clear vision.

The rays of light from a near object diverge so much that it would be impossible for the ocular apparatus to bring the outer rays to a focus upon the retina. Hence the iris contracts and cuts off the outer rays. This means slightly less brilliant illumination, but much clearer definition. It follows, of course, that the iris works harder when we are looking at near objects than for distant vision.

The marked curvature of the cornea and the aqueous humor necessarily compel them to act as lenses upon the rays of light which traverse them. But immediately behind the iris and pupil we find a special structure, an actual lens, which has to be seen to be believed, and which may well have led Darwin to confess that he could never think of the eye without wondering whether natural selection could really account for it. This is a circular, bi-convex, transparent lens, derived from the surface of the body ectoderm, like all the parts which we have hitherto studied (except the muscular tissue of the iris, which has a deeper ectodermal origin), and it constitutes the front wall of the posterior chamber of the eye, which is filled with a semi-solid, glassy material — hence called the vitreous body.

The part played in sight by the crystalline lens

The lens itself consists of a number of fibers, each originally a cell from the outer or ectodermal layer of the skin of the embryo, which has been modified into a peculiar chemical compound called crystallin. This crystalline lens, to give it its full name, tends to lose its notable elasticity in middle life, and hence becomes somewhat flatter and less convex. After its shape and transparency, its elasticity is its most important and remarkable feature, for upon this alone depends the capacity of the eye to afford us clear vision both of near and distant objects. For the lens lies in a capsule which is so connected with a circular muscle, the ciliary muscle of the eye, that when this muscle contracts the pressure upon the lens diminishes and it bulges in virtue of its elasticity. But when the ciliary muscle is not in action the lens is in a condition of considerable pressure, and is therefore flattened, and made much less powerful as an optical instrument.

This means that, so long as the lens retains sufficient elasticity, its shape can be accommodated for near or distant vision. In what is called positive accommodation, for the vision of near objects, the ciliary muscle is thrown into action, the so-called suspensory ligament of the lens

is relaxed, and the lens bulges in virtue of its elasticity, so that the rays of light passing through it (rays which, being from a near object, are diverging) are sharply bent and made to converge so as to form a clear image upon the retina at the back of the eye. But in what is called negative accommodation, the ciliary muscle ceases to act, the suspensory ligament of the lens is tense, the lens is flattened, and nicely adapted (in the fortunate and rare owners of such eyes) to focus the parallel rays of light from distant objects upon the retina.

Hence, as the names imply, it is positive accommodation, for the vision of near objects, that involves strain upon the eye. It means that not only is the iris, as we have seen, thrown into more energetic action, but that the ciliary muscle is at work; hence it is use of the eyes at short distances that is liable to fatigue them.

The focusing of our sight to suit different distances

The human eye is normally focused upon infinity. It is ready to see distant objects without muscular effort. But, by the marvelous apparatus which the nineteenth century asked us to accept as the result of the natural selection of chance variations, the eye is able to alter its optical properties, so that near objects may, on occasion, be accurately focused also. Modern man, however, reverses the proportions of work for which the eye has been evolved. It has been contrived so that positive accommodation, the act which involves strain, shall adapt it to what, in the past, have been occasional and usually little more than momentary purposes, before it returns to the sky, the horizon or the almost passive alertness for the approach of an enemy. Modern man sets this eye to work on a book for hours at a time, and then finds that it tires. We note, however, that Life has by no means finished constructing apparatus to suit its purposes. The prolonged use of the eye at short distances alters the shape of the eyeball as a whole, the constant pull of the ciliary muscle upon its attachments lengthening the eyeball from back to front, so that it becomes better suited for dealing with rays from near objects, and less strain is involved in positive accommodation. Thus we can in considerable measure permanently alter the shape of the eyeball to suit our personal purposes.

The meaning of the technical terms used in diagnosing sight

The technical names for the various conditions of the eye, from the optical point of view, are emmetropia (em = eu, or good, as in euphony, eugenics, etc.), where the eye is normal, hypermetropia for long-sightedness, myopia for short-sightedness, and presbyopia for the long-sightedness of advancing age, due to the diminished elasticity of the lens. These various conditions of the eye are of much importance for health, and will be dealt with elsewhere in this work. Their importance, however, is purely mechanical, and they need not further concern us here.

Hitherto we have been discussing nothing but mechanical devices for admitting rays of light, regulating their quantity, and refracting them. We now come to the retina, or curtain, at the back of the eye, on which inverted images of external objects are thrown by the action of the cornea, the lens and the other refracting media of the eye. The retina is essentially a nervous structure. Historically, as we have seen, it is a bulb of the brain, and it is extremely rich in nerve-cells. Anatomists commonly distinguish eight layers in the retina.

The rods and cones or characteristic visual cells of the eye

The foremost layer consists of six-sided cells which are deeply pigmented. Immediately under them we encounter the characteristic visual cells, known from their shape as the rods and cones respectively.

These form a well-marked palisade of cells under the pigmented layer, and they are regarded as modifications of the cells which line the internal cavity of the brain. This we can readily understand if we remember the history of the retina. But these visual cells have been profoundly modified for a special function.

They are not nerve-cells, as indeed their historical origin shows, but they are the cells which are immediately affected by light, and they are in intimate connection with a vast number of nerve-cells and with the terminals of the optic nerve.

Except in one area, the rods are much more numerous than the cones. Each rod has an inner and an outer segment, the latter a cylindrical pile of very thin discs deeply colored with a pigment known as "rhodopsin" or visual purple, which is chemically sensitive to light, and especially to the blue and violet rays, just like the sensitive films used in photography. As shown on page 2632, the cones are different in shape, and their outer segment is practically colorless. At what is called the yellow spot of the retina, near its middle, the cones alone are found, and hence the marked contrast of its color. Both rods and cones are living cells, with nuclei, but these nuclei are found at a considerably deeper level in the retina. There is a marked resemblance, on the whole, between the arrangement and distribution of the nerve-cells in the retina and the nerve-cells in the cortex cerebri — a fact which our historical knowledge of the retina as a projection of the brain itself helps us to understand.

The blind spot where the optic nerve enters the eye

About one-tenth of an inch towards the inner side of the eye from the yellow spot, the optic nerve enters the eye. Here the retinal elements themselves are absent, and hence this spot is blind. The presence of this optic disc or blind spot in the eye can readily be demonstrated by means of this diagram.

If we close one eye, say the left, and look at the cross with the right, at a certain distance the dot will be invisible, though when we move the page nearer, or further, it comes into view again. At the distance at which it disappears, the rays from it fall on the blind spot, provided that the eye be fixed on the cross, so that the rays from it fall upon the yellow spot of the eye.

Though the rods are highly specialized, and though their pigment is rapidly changed, by the action of light, first into yellow, and then into white, yet it is believed that the capacities of the rods are limited, and that they do not serve to distinguish between colors. Much higher in development, and later in the evolutionary record leading up to man, are the cones and their concentration in the yellow spot. At this spot it is evident that everything is uniquely favorable to acute vision. Here the retina is exceedingly thin, not laden with supporting fibers, nor with blood-vessels of any size. When we look at near objects the two eyes slightly converge, so that the rays received by both eyes may fall upon the yellow spot of each retina.

What optical experiment shows of the action of the rods and cones

Careful optical experiment has proved that the cones, and no other level of the retina in this area, are the visual terminals; and it has been found that in visual fatigue the chromatin of the nuclei of the cones tends to disappear. It has further been shown that two objects, such as the points of a pair of compasses, which can be seen as two so long as the rays from them impinge upon the yellow spot, can only be seen as one when the rays strike upon any other part of the retina. Two objects so near together — for instance, as double stars — as to affect only one cone, only afford one image. In order to get two images, two cones must be involved; and the reason why the compass-points are seen as double by the yellow spot, but not by any other part of the retina, is that in other parts the cones lie further apart, being diluted, so to speak, by the rods.

Much attention has lately been devoted by psychologists to the special functions of the rods and cones respectively. They have observed that colors are not distinguished appreciably by the outermost parts of the retina, and that there the cones are very few. They have noticed, also, how the yellow spot and the cones are found only in the very highest type of eyes; and careful experiment has led to the conclusions thus summarized by Dr. McDougall:

The rods the means of sight in a dim light

"The function of the rods is to enable us to see in light so dim that it cannot stimulate the cones. We may regard the rods as representing a primitive form of visual sense-organ from which the cones have become differentiated and specialized. In ordinary daylight our visual sensations are excited through the cones only, for the rods are kept in a state of exhaustion by so bright light. [We saw how light bleaches the visual purple of the rods.] But when the eyes have been shielded from bright light for some minutes, the rods regain their sensitivity. Hence on entering a dimly lit room, or on going out of doors from a brightly lit room on a moonless but starlit night, we can at first see little or nothing, for the cones are insensitive to so dim a light, and the rods are exhausted. After a few minutes, the rods having regained their sensitivity, we can see the outlines of objects, and differences of light and shade, but no colors for the rods mediate only one quality of sensation — a slightly bluish-gray, of small range of intensity.

"If, then, one looks at a small object, such as one of the dimmer stars, it will be found to become invisible as the eye is turned directly upon it, for its image then falls upon the central region of the retina in which no rods are present. Since the rods mediate a single elementary sensation-quality, no matter what be the kind of light falling upon them, and since they are sensitive to light too dim to affect the cones, the solar spectrum, when made of very low intensity, appears no longer as a band of colors, but as a band of dim gray light a little shortened at the red end. The shortening at the red end is due to the fact that, while the rods are sensitive to rays of all other parts of the spectrum, they are insensitive to the red rays or rays of greatest wave-length.

"It has recently been shown, also, that the rods respond to stimulation less rapidly than the cones, so that the sensations resulting from the stimulation of them appear in consciousness an appreciable interval after those due to simultaneous stimulation of the cones."

The cones responsible for sight in bright light and for discrimination of color

These facts are extraordinarily interesting. The older type of organ, the rod, is *more* sensitive, we observe, in mere terms of quantity. It will respond when the cones show us nothing, so that a faint star, seen slightly askance, disappears when we look straight at it and its light falls on cones only. On the most obvious and commonly accepted criterion of sensibility, the rods are thus of a higher order than the cones. But this case teaches us what is abundantly true in the analogous case of the ear — that the true measure of sensibility is not quantitative but qualitative. The rods may be able to see where the cones cannot, but all colors are one to them, and they have nothing like the same powers of discrimination, apart altogether from color, that the cones have. It becomes an interesting question for general, as distinguished from human, psychology to decide whether the qualities of color sensation are appreciated at all by those creatures in whose eyes the cones and the yellow spot are not to be found. And we are also entitled to argue, from the size of the yellow spot in ourselves, and from the quite astonishingly large area of the cortex cerebri which is associated with vision, that in man the development of this sense is preëminent, even though he may be neither hawk-eyed nor lynx-eyed.

Color-blindness seldom due to defect in cones

When we learn that the cones are responsible for our discrimination of colors, we seem to have in our hands the key to color-blindness, which we might expect to be due to defect of the cones. That is true of the very rare cases of complete color-blindness, in which it is found that the retina is blind where the rods are absent, which means that the cones, though present, cannot perform their functions at all. But in other cases of color-blindness the peculiarity is more subtle. The cones are present and perform their functions, but certain definite defects exist in the individual's color-vision.

These defects have now been shown in many instances to obey the Mendelian law of transmission by heredity; and this suggests that, as in many other cases of Mendelian transmission, the factor at work is chemical. Further, cases of partial color-blindness, such as are met with every day, usually depend upon the lack of capacity to see certain particular colors, such as red or blue.

Dr. Young's theory of color-vision in combinations

Evidence of this kind affords a theory of color vision which has several variants, but is essentially one and the same in all cases. This is the theory, first suggested by Dr. Thomas Young, the founder of the wave-theory of light, that our visual apparatus contains a few units — whatever they may be — three or four in number, each of which is capable of appreciating a particular color, and that our appreciation of all the infinite varieties of color is due to varying blends of these few. According to Young, red, green and blue are the primary colors, for each of which our eyes have a special apparatus; and all other qualities of color-sensation, including white, are fusions of these three elementary qualities, or of two of them. To these three, as defined by Young about a century ago, we must now add the special grayish "color", if so it can be called, which is peculiar to the function of the rods; and we seem therefore compelled to believe that in the visual area of the cortex cerebri there must be four distinct substances, or sets of substances, each concerned in the production of one of these four primary elements. Color-blindness thus becomes intelligible in chemical terms, as due to the defect of one or other of these substances; and we can dimly imagine how such a chemical peculiarity, like many others, may be capable of Mendelian transmission in heredity.

Innumerable optical problems are raised in the discussion of the mechanics of vision, as, for instance, in the muscular apparatus by which the two eyeballs are moved together These are very important for the oculist who has to deal with a squint, for instance, but they matter little to the student of man as a whole.

The visual memory in people who have become blind

Much more to our purpose is the final question as to the seat of visual memory, and of the various processes of visual recognition, the combination of sensations to make a whole which we call perception — the process illustrated in "puzzle-pictures" — and the recall of visual perceptions and construction of new ones by the "inward eye". On this point the evidence is clear. Visual images cannot be called up by those born blind, or those who have lost their sight at as early an age as two years. But if vision has been enjoyed in the ordinary way, and then the eyes lose their functions, or are even removed by the surgeon, clear and distinct visual images may still be seen by the outwardly blind man. This is conclusive proof that the eye is not the essential factor in this process, though the past functioning of the eye is necessary. But if the visual area of the brain be destroyed or thrown out of action, no visual images will be formed. Hence we know for certain that it is the visual area of the brain which remembers, recalls and creates But what is the full significance of those three verbs we cannot realize until our psychological studies have gone deeper.

The glories of the inward eye lit by memory and thought

Meanwhile, we see that the eye is merely machinery for transmission, and that both vision and the memory of vision, leading even to the artist's and the prophet's conceptions, are achievements of the brain alone. A Homer or a Milton may lose the functions of what we call their eyes, and become blind. But the inward eye remains. If it has been made "a mansion for all lovely forms", it can still see beyond the darkness of the present and the grave Such blind men are seers still.

CARRYING ON LIFE'S TORCH

Cells and the Reproduction of New Individuals

by
HUGH DANIEL REED

As we pointed out in a previous article, animals, like all other living things, are made up of basic units called cells. In unicellular animals, the entire body consists of a single cell. In other animals, called multicellular, there are large numbers of cells; there are billions upon billions in the higher animals.

The body of an animal becomes bulkier through an increase in the number of cells. This increase is brought about through the process called mitosis, or indirect division: the mother cell divides and yields two daughter cells, each of which is like the mother cell. Something entirely different is involved when an animal reproduces its kind. In this case we have, not the division of old cells, but the formation of an entirely different kind of cell. This fundamental change in the basic units of the animal's body is the important element in all reproduction.

The plan of organization of the body

Before we consider the manner in which animal cells give rise to basically different cells, let us set forth briefly the plan of organization of the body. The cells are of many different kinds, each kind performing various specialized services. Cells are combined to form four different kinds of tissues. These are (1) the protective, or lining, tissues that cover the outer surface of the body and that also line certain internal organs; (2) the contractile, or muscular, tissues; (3) the connective and supporting tissues; (4) the conducting, or nervous, tissues. In their turn tissues are grouped together to form still larger and more complex units—the organs, such as the stomach, the gullet, the intestines, the lungs, the liver, the kidneys and the heart. All organs, again, are combined to form systems of organs, such as the digestive system, the respiratory system, the circulatory system, the excretory system and the nervous system. Finally, the various systems of organs are knit together to form the living organism itself. Thus, from the standpoint of structure, the animal body represents a repeated combining of simpler units to form more complex ones.

The division of labor in the body

There is a parallel in human society, in which individuals are grouped together to form various larger groups; these are then combined to form the community at large. The governing principle of this type of organization is the division of labor; each element of the community performs certain assigned services. So it is with the body. Each system, each organ, each tissue and each cell has its particular duties to perform. The digestive system, for example, changes the chemical structure of food so that it may be absorbed by the different parts of the body; the vascular system (blood and lymph) distributes food throughout the body. And so it goes through the entire range of systems and organs and tissues and cells. It is clear, therefore, that no part of the body is sufficient unto itself; it is dependent upon every other part of the body for some measure of support.

There are eight systems of organs in the body. (1) The dermal system, comprising the surface parts of the body, is concerned with the matter of protection from within and without. Through the dermal system the organism communicates with the outside world. (2) The skeletal system, com-

prising the bony and cartilaginous elements, gives form, stature and support to the body. This system is inert in the performance of its duties. (3) The muscular system moves the body and its parts. Its elements, unlike those of the skeleton, possess an intrinsic activity. (4) The vascular system serves in the capacity of a transportation system, conveying materials to and from body substance. (5) The kidney or urinary sys-

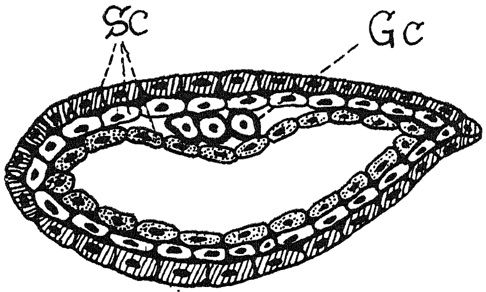


FIG. I.
Schema to illustrate the two foundation groups of cells in the animal body. S.c., somatic cells; G.c., germ cells.

tem, is responsible for the elimination of nonvolatile waste in the form of urine. (6) The respiratory system is the place of oxygen intake and carbon dioxide output. (7) The nervous system serves the purposes of communication between parts of the body and of stimulating parts to act. It is the outstanding system in the coordination of the diverse body components. That is, the nervous system assists in causing the many different parts to act harmoniously.

The organ systems mentioned above are intimately related to the life of the individual. The cells of which these organs are composed are the seat of the vital activities which are called collectively metabolism. That is, the sum total of all vital activities constitutes the metabolism of the body. These cells when viewed from the standpoint of both structure and physiology are called somatic cells since they form the soma or body.

There is an eighth system, the reproductive, comprising two general types of cells playing widely different roles. One of these cell groups is the somatic, concerned with the metabolic activities as they are everywhere. The other group is known as the germ cells which are set aside for reproductive purposes only. They take no part in the general metabolism of the body but are lodged among the somatic cells by which they are protected and nourished. The protoplasm of these cells is called the germ plasm. The germ cells do not differentiate into tissues but remain in a primordial or youthful state as it were. Figure 1 illustrates the general nature and relations of these two fundamental groups of cells in the body.

The reproductive system as a whole is found to be more important to the species or kind of animal than to the individual, because the continued existence of every kind of animal depends upon its success in producing offspring which, when mature, may in their turn reproduce. When viewed in this light all the functions in the body of the individual are subordinate to the reproductive function, so far as the species is concerned. One might consider that an individual animal maintains itself in order to produce others of its kind. And after all, with most animals the individual is not important. Zoologically speaking, the main business of the animal is to reproduce its kind in order to maintain the species. For the present the essence of the reproduction only is necessary.

The significance of reproduction is this; it represents the beginning of a new individual of the species, and in reproducing or in producing a new individual two reproductive elements are involved. Most persons are familiar with these elements, one being the egg and the other the spermatozoon, or zoosperm. The egg, speaking of it in a relative way, is large and immotile. The zoosperm is always minute and motile. These peculiarities are demonstrated by E and S in Figure 2. The zoosperm is elongate and slender and possesses a vibratile tail-piece or flagellum the vibration of which in a liquid medium en-

ables the zoosperm to propel itself as a free and independent organism, which it actually is. In a study of the relative size of the egg and the spermatozoon one encounters a great many difficulties because there are great variations The larger the egg the greater the relative difference between its size and that of the sperm. One may consider that the egg is macroscopic (visible with the naked eye). Though visible, there is great variation in the size of the eggs of animals. There are zoosperms which are a million times smaller than the eggs of their kind. Very important is the observation that the spermatozoa are motile. The names of these elements used above are the common ones. There are other terms which are much more satisfactory. The egg and the zoosperms are known collectively as gametes. Each is more specifically designated by a prefix referring to the relative size of each. The egg being larger is known as the macrogamete, the spermatozoon being smaller is known as the microgamete. These gametes are ordinarily produced by different individuals. Those producing eggs are referred to as the females, and those harboring the spermatozoa are known as the males. The word sex means to cut in two, and is a reference to the division of individuals into two groups according to the kind of gamete which each harbors or produces.

The role of these gametes in reproduction introduces the cellular phase of this process. A new individual is not created until these two elements meet and fuse. The zoosperm (microgamete) due to its motility comes in contact with the egg (macrogamete) which it enters. The fused gametes constitute a new individual, which in this stage of the reproductive process is known as the zygote. That is, as soon as these two elements have come together and fused a new individual has come into existence. This fusion of gametes is commonly mentioned as the fertilization of the egg. Fertilization is also known by the name syngamy, which refers to the fusion or yoking together of the two gametes. Syngamy then means sexual reproduction, which comes near being a universal method among animals.

The reproductive function of the two gametes, or sex elements, is their mating and fusing in syngamy or fertilization. This means a yoking together of the two elements so as to form one distinct element, the zygote, which is a new individual. This is just as much a distinct organism as it is after development and growth has brought it to maturity, although in the zygote stage the new individual is still in a potential state.

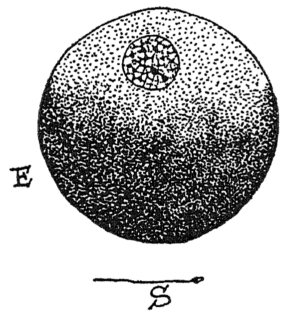


FIG. 2.
Diagram of egg (macrogamete), e, and a zoosperm (microgamete), s, illustrating the relative difference in size.

The place where syngamy (fertilization) takes place varies among animals. In man, the hairy quadrupeds, birds, and some others this event occurs within the body of the female and it is therefore mentioned as internal fertilization. In other animals, as the frog, for example, the eggs and sperm meet in the water outside the body and is called accordingly, external fertilization. In cases where eggs are fertilized in water outside the body of the female the process must be performed quickly, for while the life of the zoosperm varies in duration in different animals it is relatively short. These minute sperm are not supplied with materials that provide them with an unlimited amount of energy. Those energy producing materials stored within the sperm are soon

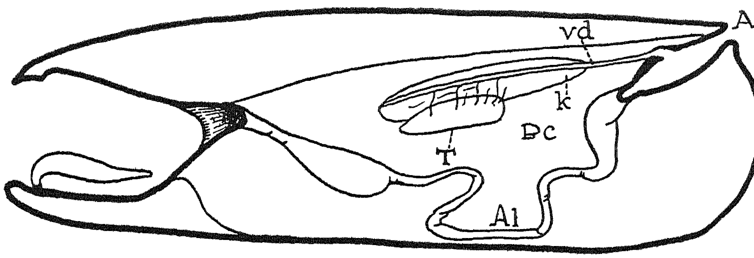


FIG. 3.
Schema of frog's body. a, anus; al, alimentary canal; bc., body of abdominal cavity; k., kidney; t., testis; vd., vas deferens.

depleted, after which time death results. As soon as they become inactive fertilization can not take place. The real job of the zoosperm is that of swimming actively so as to come in contact with the eggs. The ability to move about rests entirely with the zoosperm of the two gametes.

Since fertilization must immediately follow the voiding of the sperm, it means that something more than casual provision must be made for immediate contact of the two elements. This may be taken as an index to the general role enacted by the genital system. The genital organs must be so constituted as to structure and relations of parts as to perform three functions. The first is that of protecting and nourishing the elements until the time comes for their participation in syngamy. There must be some place in the body of each of the sexes for harboring these elements. The second is that the structural organization will be such as to insure the safe conduction of the gametes to the exterior or to that place where they normally should meet in any given species. The third, is that they must be left in such a state as to survive and meet. With these three general functions in mind the important points in the structure of the genital organs may be summarized. The central organs where the gametes are harbored are known as gonads. This term may be applied to the organs of either sex. Those of the male are called the testes. These organs in their typical (primal) position in back-boned animals are found suspended in the posterior half of the abdominal cavity underneath the kidney as shown in Figure 3 of the frog. The testes are not extensive organs although millions of zoosperms are produced in each. In passing from the lower to the higher back-boned animals there is found a tendency for the testes to move in a posterior direction to the very posterior part of the abdominal cavity, and finally, in the hairy quadrupeds, they push outside the body limits itself, carrying along thinned portions of the body walls to form the scrotal pouch in which they are lodged (Figure 4). The function of the testes is that of harboring the zoosperms until they are mature and capable of fertilizing an egg. When mature the zoosperms leave their moorings in the testis and are conducted to the exterior through a tube known as the vas deferens.

The central organs of the female corresponding to the testes of the male are the ovaries, located typically in the same place as the testis of the male. Within the walls of the ovary the eggs mature. The escape of the eggs and their course toward the exterior is different from that which prevails in the male. The eggs when ripe, instead of releasing themselves from moorings in a central cavity of the organ, break through the walls of the ovary and virtually fall into the abdominal cavity. On either side of the abdomen there is a tube, the oviduct, which conducts the eggs to the aperture leading to the outside world. In such animals as the hairy quadrupeds, which give birth to living young, the posterior portion of the oviducts is enlarged and otherwise modified to form the uterus in which the eggs develop.

It appears that the structural parts of the genital system in both male and female are advantageously arranged to

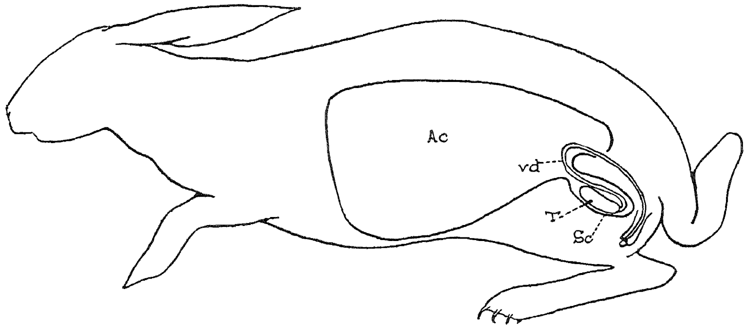


FIG. 4.
Schema of hairy quadruped's body. Ac., abdominal cavity; Sc., scrotal pouch; T., testis; vd., vas deferens.

serve the needs of the germ cells during the long and complex processes through which they pass in the production of a new individual.

It has been stated above that the germ cells do not participate in the metabolic activities of the body. But out of the germ-cell group there have differentiated two kinds of cells. In the body cells one finds that differentiation has gone on so as to produce groups of cells which differ from one another and are called tissues. The germ cells differentiate to form the two gametes, each differing from the other in many details. There is considerable significance to be attached to the differences between the gametes. The macrogamete is large because its cytoplasm is filled with yolk, which is to be used as the food for the development of the new individual. The great stores of this sort, crowded into the cytoplasm of the egg have resulted in its greater size, and it is due to the presence of yolk that the egg cells of all animals are larger than either the zoosperms or other cells of the body. Wherever one finds great variations in the size of eggs it is due to a variation in the amount of yolk present. For this reason the eggs of birds are the largest of all cells. In the case of the zoosperm which is minute, one finds that yolk is absent, and there is only a small amount of cytoplasm. Since the long flagellum is responsible for moving the microgamete in a liquid medium it always moves with the opposite end foremost, and for this reason this portion of the zoosperm has come to be known as the head piece (Figure 5). The slightly narrower portion between the head piece and flagellum is known as the middle piece. The head portion contains practically nothing but nucleus, surrounded by a very thin envelope of cytoplasm. The centrosome is located in the middle piece just behind the nucleus. By means of such a comparison one comes to appreciate the differences between these two gametes when viewed as cells, which they actually are. So far as the nucleus is concerned each cell is the equivalent of the other. That is, there is in this minute zoosperm the same chromatin material that is present in the nucleus of the egg.

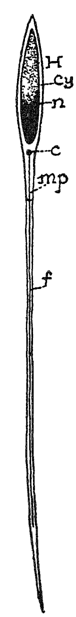


FIG. 5.
Diagram of zoosperm. H., head piece; c., centrosome; cy., cytoplasm; f., flagellum; mp., middle piece; n., nucleus.

The nuclei are the essential parts as regards reproduction. It is in connection with the differences in size and motility that one sees the advantageous division of labor which has been worked out in these cells. The germ cells are not only set aside from all others in the body but differentiation has ladened one, the egg, with stores of food, rendering it immotile, and provided the other with small

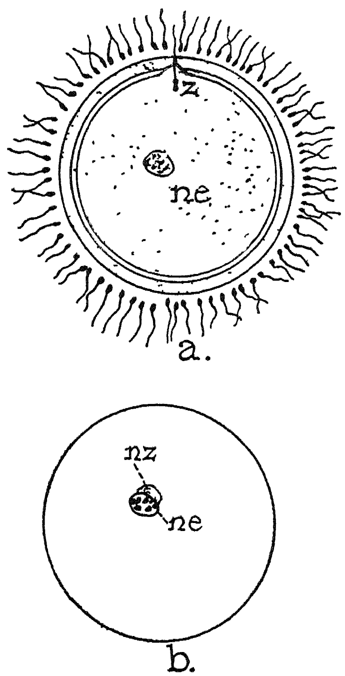


FIG. 6.
SCHEMAS ILLUSTRATING FERTILIZATION.
a., egg; b, fertilized egg (zygote), ne., nucleus of egg; nz, nucleus of zoosperm, z., zoosperm entering egg.

size and motility. That is, the egg supplies the food for the new individual which is to develop from the mating of these two cells. The zoosperm, because it is not loaded down with this excess baggage in the form of yolk, can move about actively in a liquid medium and insure the necessary meeting of the two.

The details of fertilization are numerous, but the whole question can be reduced to simple statements. The relations which come about between the egg and the zoosperms at the time of syngamy are shown diagrammatically in Figure 6. One notes that there may be thousands of zoosperms which come into actual contact with the surface of the egg, but ordinarily only one gains successful entrance. For every single egg that is produced by a female there are probably millions of zoosperms produced by the male. The difference in numbers is so great that the fertilization of the egg would be assured without anything in the way of special attraction existing between the two gametes.

As soon as the sperm enters, which requires a brief interval of time only, the headpiece begins to enlarge, so that it becomes difficult to distinguish the nucleus of the egg and that of the sperm. While they may be said to fuse with one another they actually come close together, but each retains its own identity for a time. The two nuclei which have mated in this fashion behave as a single nucleus, as may be determined by following the subsequent divisions of the fertilized egg (zygote or new individual). When the zoosperm has entered the egg it moves toward the nucleus of the latter, and from that time on the two distinct nuclei behave as a single nucleus.

The gametes, egg and zoosperm, are true cells. There is in each a nucleus surrounded by cytoplasm, with its usual relations and functions to perform (Figures 2 and 5). The manner in which these cells are enabled to take part in the reproduction of new individuals will be outlined in the paragraphs which follow.

It is important to observe that because of syngamy the cytoplasm of the two gametes is fused and the nuclei are so associated that they function as a single nucleus. That is, the zygote though the result of the fusion of two cells is itself a single cell, in which state all multicellular animals begin their existence upon the earth.

In the chapter called Chromosomes in this volume, the point is made that in any given species of animals, each individual cell in

the body has a normal and constant number of chromosomes. That being the case one might expect that each time a new individual is formed by the complete fusion of two cells that the chromosome number would be doubled. But it may be determined by observation that this is not the case. This leads one to suspect that the functional gametes are in possession of only half the number of chromosomes normal to the species. Study substantiates the suspicion. Those germ cells in both sexes which are destined to become functional gametes (eggs and sperm) pass through a series of changes involving the nucleus mainly. This process is known as the maturation of the germ cells. It is a period during which the germ cells grow into gametes capable of completing their respective roles in reproduction. In brief, the maturation of the gametes means the conditioning of these elements to take part in syngamy without doubling the number of chromosomes. The reduction of the number of chromosomes, of course must come about before fertilization.

The process of maturation which results in functional zoosperms is called spermatogenesis. This word means the genesis or origin of sperm. The process resulting in eggs or ova is called oögenesis, meaning the origin of eggs. At the end of this process of maturation both gametes being provided with only half the number of chromosomes they are said to be in the haploid state. The word haploid means simple-like. That is, the reduced number when compared with the normal number is a much simpler state. When the full number is restored again following syngamy (fertilization) the state is said to be diploid, which means two-fold, a direct reference to the doubling of the number of chromosomes. The outstanding accomplishment of the maturation of the germ cells is the reduction of chromosomes to the haploid state. The normal diploid state being restored at fertilization, it is obvious that the zygote is a true single cell both structually and functionally. Although the nucleus of the zygote is to be regarded as representing a combination of two different nuclei, they behave in such a way that one recognizes a single nucleus. These features are illustrated by Figure 6.

Since the chromosomes are the bearers of heredity traits the new individual inherits from both parents, half of its chromosomes coming from each. This is known as biparental inheritance (Figure 7).

There is another important phase in reproduction where cells are significantly involved. The question is, how does a single cell become a many-celled individual? Studies bearing upon this phase of reproduction constitute the science of embryology. This science is concerned with the development of the embryo which sooner or later comes into existence. The object of this study of development is not to be found in the setting forth of the facts and principles of embryology as a science, but rather that of discovering the manner in which a single-celled zygote becomes a multicellular animal, with all the organs and systems of organs that may be found in the adult. Knowing that the zygote is a single cell, and that all of

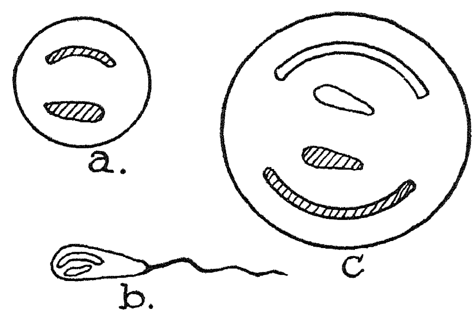


FIG. 7.

Schemas showing haploid and diploid state of chromosomes in gametes and zygote assuming that the normal (diploid) number is four a, functional egg and b, functional zoosperm each with the reduced (haploid) number of chromosomes. c, zygote (fertilized egg) with the diploid number of chromosomes, half having been contributed by each gamete and therefore illustrating the basis of biparental inheritance.

the cells of the body possess the normal number of chromosomes it may be judged that the general process of development is concerned with cell division of the mitotic sort since this is the method of division which provides for the same chromosome equipment in both mother and daughter cells. The fertilized egg (zygote) being a normal and typical cell in every respect, the first activity in the way of development is recognized in the division of the zygote into two cells. The first two cells thus formed remain in contact (Figure 8, a). The division of the zygote is known as the segmentation of the egg, as if the egg were broken up into two segments. Segmentation, division and cleavage are terms referring to this process. The process of division continues (Figure 8, b) and there is soon reached a stage in which the cells are much smaller than the first cells formed. If a transection were made of the individual in this stage it would be found that the cells had arranged themselves in a single layer so as to form a cavity within the whole mass (Figure 8, c). This cavity within is called the segmentation cavity (Figure 8, Sc.), meaning that during the segmentation of the fertilized egg the cells have become so arranged that they leave a space in the center of the mass. The new individual is actually a hollow ball of cells. In this stage the new individual is no longer a zygote, nor is it an embryo. The name of blastula has been given as one for this stage, the word meaning a germ, and the reference being that this hollow ball of cells is to give rise to an embryo. From this point in the development the general process is that of a rearrangement of the cells of the blastula. Through invaginations and proliferations the cells become arranged in layers which are called the primary germ layers. The first two layers formed are named according to their relative positions ectoderm and entoderm (Figure 8, d). Between these the third germ layer is formed and because of its middle position with reference to the other two layers it is known as the mesoderm (Figure 8, e). These three germ layers furnish the materials, as it were, out of which all the organs of the body are fashioned.

The foregoing review, the writer hopes, may serve to emphasize the observation that animal reproduction, like other phases of the study, is founded upon cells and cell behavior and that the nucleus of the cell is an extremely important factor.

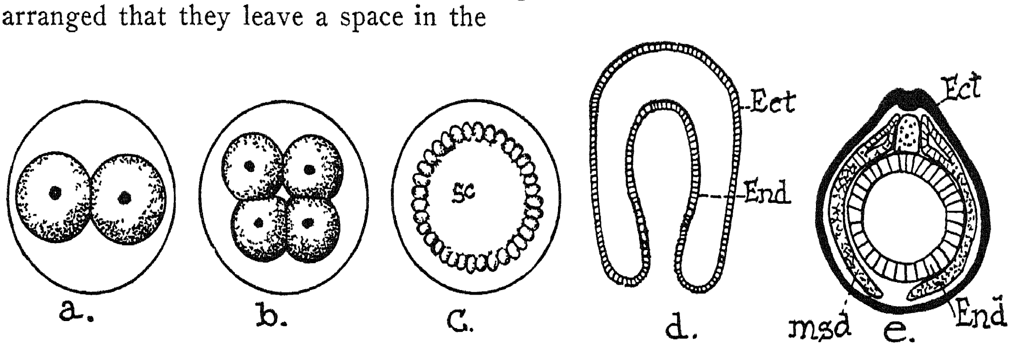


FIG. 8.

Diagrams illustrating the early development of the zygote a, the two-celled stage; b, the four-celled stage; c. the blastula stage with segmentation cavity, sc., d and e illustrating the position of the primary germ layers, ect. ectoderm, end, entoderm, and msd., mesoderm.

PLANT SCOURGES

Weeds—A Standing Menace to Our Fields

by
CLYDE M. CHRISTENSEN

A PLANT can be a thing of beauty but not a joy forever. The bright trumpets of bindweed, a pasture sunny with buttercups, Queen Anne's lace in a meadow — here are spectacles to delight the passing motorist. But the farmer finds them less delightful, for the bindweed strangles his corn, the buttercups contain an irritating juice that cattle dislike, and Queen Anne's lace, which is a wild carrot, harbors a destructive weevil. These, and other plants that spring up unbidden, the farmer calls weeds. This name has nothing to do with plant classification. A weed is any plant growing where it is not wanted.

A dandelion in the front lawn is a weed; it is not a weed when cultivated for fresh greens. Sweet clover sown in the meadow is not a weed; when some of the ripe seeds drift over on the wind to the flower garden, they grow into weeds.

Weeds do enormous harm. In actual figures, many billions of dollars a year are lost, over the world, because of weeds. The sum is greater than the combined loss due to both plant diseases and insects. The loss is likely to be highest in regions where agriculture is most intensive and where the crops and land are of greatest value, but weeds in open-range country are also costly.

The cereal-grain crops offer a good example of the tax we pay on weeds. Seeds of weeds in the grain field are harvested along with the grain. On the average, wheat brought to the elevators contains one per cent of weed seeds. This means that in, say, a billion-bushel wheat crop, ten million bushels of weed seeds were harvested, threshed, stored, hauled to mills or terminals and there removed and disposed of. Even a very small percentage of seeds of certain weeds, if blended with the grain, would give an off flavor to the flour. The grower is "docked," that is, receives a reduced price for his grain when it contains weed seeds.

Weeds that grow in hay or forage crops are of low feed value; many of them are unpalatable to stock, and some are actually poisonous and cause the loss of valuable animals. Others, when eaten by cows, give an unpleasant flavor to milk and butter. Weeds with pointed or spiny seeds or seed pods may get caught in the coats of animals, causing acute discomfort and also reducing the value of wool or hides.

Along railroad rights of way and highways, weeds are often fire and traffic hazards. Weeds clog drainage and irrigation ditches, canals and waterways. The water hyacinth, imported to Florida from the tropics, in a short time blocked many coastal and inland waterways. Constant and costly work is required to keep these channels clear. The same weed introduced into Europe became an even worse pest.

Some plant diseases have spread by means of weeds. The stem rust of wheat is caused by a fungus that spends part of its life on the barberry. To aid in controlling this disease, millions of ornamental barberry bushes have had to be uprooted and destroyed. The blister rust of white pines is caused by a fungus that spends part of its life on the leaves of wild and cultivated currant bushes. Some virus diseases that attack cultivated plants may be traced to weeds which not only serve as a source of the virus but also furnish a breeding place for leaf hoppers, aphids and other insects that are carriers of these viruses. A number of insects that directly injure cultivated

plants breed on or in weeds.

Hay-fever sufferers know that ragweed (as well as some other weeds and cultivated plants) causes heavy human misery. Poison ivy, poison sumach and other weeds are even worse pests than ragweed.

Probably the greatest harm done by weeds is in competing with crop plants. The weeds grow rapidly and send strong root systems far into the soil. In less than three weeks of growth, a vigorous mustard plant in a grain field will produce more than four hundred feet of roots. A dozen of these plants will produce nearly a mile of roots in three weeks. They rob the crop plants of soil minerals and water, and their leaves screen sunshine from the cultivated plants, further reducing the grower's yield.

Many weeds have remarkable powers of reproduction. An average-sized pigweed will produce from 100,000 to 200,000 seeds in one season, and a large pigweed may ripen 10,000,000 seeds. An annual crop of about 20,000 seeds per plant is a good average for each of 200 different kinds of annual and perennial weeds.

The seeds of many weeds are tenacious of life. In a famous test in Michigan, the seeds of twenty different kinds of weeds were buried in the soil (too deep for growth) in 1879. After forty years, some seeds of ten of the kinds were still able to germinate and, after sixty years, seeds of two kinds were still viable (able to grow). Nearly 70 per cent of the seeds of one weed, the moth mullein, germinated after having been buried in the soil for sixty years.

The seeds of some weeds can lie under water for months, or even years, and can still remain viable.

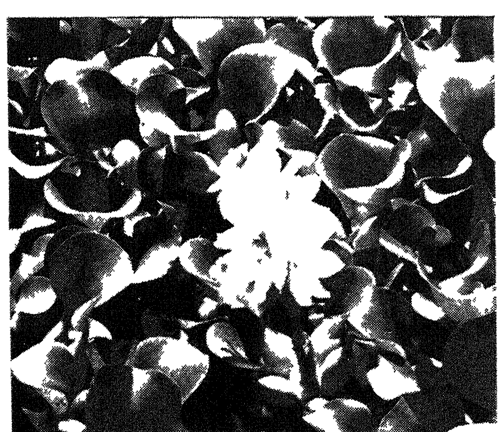
Quackgrass and certain other weeds can multiply rapidly by underground root stems or by root fragments. Perennial sow thistle and wild morning-glory, two of our most pestiferous weeds, not only produce seeds in abundance, but can also grow from severed roots. A small piece of morning-glory root carried into a field may in one year produce a root system fifteen feet across and extending down twenty feet into the soil. When these roots are cut by a cultivator, each piece will send up a new plant.

Weeds are famous travelers, and every continent today has a weed population made up of both native and immigrant pests.

The seeds are carried in almost every imaginable way. Those of the dandelion and some thistles have a buoyant parachute, called a pappus, on which they can ride for miles, drifting along with the wind. Many burrs, the beggar-ticks and others, have sharp or barbed spines by means of which they attach themselves to the fur of animals or the clothing of man. The puncture vine, a native of the Sahara Desert, has been spread by railroads and is now at home in many fertile lands. Motor cars and airplanes also carry it; the seeds cling to the tires and may be dropped off hundreds of miles from where they were picked up.

Animals and birds swallow seeds whole and later excrete them. When livestock are shipped long distances, seeds are transported in this manner. Farm machinery, especially harvesting machines and threshers, will carry seeds from one field or farm to another. The seeds of a few weeds can be carried by streams or by the water in drainage or irrigation ditches.

Man has only himself to blame for some of the weeds that plague him. Most of North America's worst weeds, for example, are aliens, brought from the other continents. The early colonists, when they set out from the Old World, brought seeds of plants to raise in the New. Almost no at-



Standard Oil Co. (N. J.)

Water hyacinths. These plants, imported to Florida, have become a pest, blocking waterways.

tempt was made to insure the purity of this seed stock, and so the common weed pests of these plants came along, too. Before 1700, dozens of different weeds common in Europe had a foothold in New England, and, as time passed, hundreds more were brought in. Not all of them prospered, but many did. Among them was the plantain.

Here are a few examples of weeds that thrive far from their native heaths.

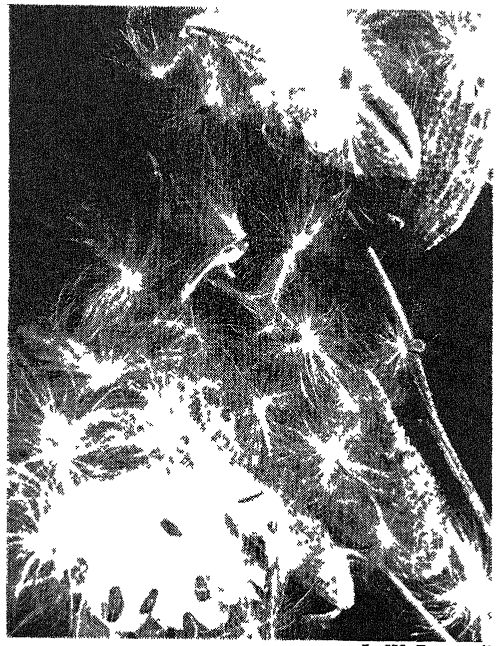
Russian thistle — tumbleweed — was unknown in the United States before 1873. At that time a small amount of flax seed containing some thistle seed was imported and planted in South Dakota. Within ten years the Russian thistle had spread extensively in South Dakota and Missouri, and within another ten years it had infested sixteen states, from Missouri to the west coast.

The Canada thistle is not native to Canada but was brought from Europe early and became established around Montreal. When General Burgoyne's army invaded New York from Canada in 1777, hay brought for the cavalry horses contained thistle seeds. The Americans soon got rid of Gentleman Johnny Burgoyne, but the Canada thistle is now a costly pest in thirty-six states, from coast to coast.

Johnson grass, brought from Turkey, was tested as a forage grass in California. It proved of little value, but soon escaped and became a most detrimental weed along irrigation ditches.

The prickly pear, a kind of cactus, was introduced into Australia from North and South America for use as an ornamental plant. Within a short time it had taken over hundreds of thousands of acres of valuable agricultural land and amounted to almost a national calamity.

If a piece of land is stripped of vegetation and then left idle, weeds are the first plants to take over, and they take possession of the land in definite order. First, annual weeds form a dense cover. They not only hold the soil in place but also, as they rot, enrich the soil. Gradually the annual weeds are replaced and crowded out by biennials, which have the advantage of a two-year lease on life. The biennials are crowded out by perennials. If the climate



L. W. Brownell

The seeds of the milkweed, shown above, are carried far and wide on their buoyant "parachutes."

is suitable, these in turn may give way to forest trees. The trees will persist until fire, flood or other violence of man or nature again lays the ground bare, when the cycle begins anew. You can see the beginning of such a cycle, on a small scale, on newly filled-in lots or abandoned garden plots or even in untended yards around vacant houses in city or country.

Man fights the war of weeds with a variety of weapons, old and new. No one method of fighting will control all weeds, and certain weeds can be stamped out, or checked, only by the use of several methods at the same time. The attack to be chosen depends on the weed concerned, the extent of its infestation, the location and the purpose for which the land is used.

Governments long ago recognized the danger of importing alien weed seeds mixed with other seeds and the danger of introducing new cultivated plants that might become pests. Plant quarantine laws are helpful in this connection. Where there is such a national plant quarantine, seeds, plants or plant parts for propagation can be brought into a country only after rigid inspection at

the port of entry; and new plants brought into the country are tested in isolated plots. The tests not only show whether the plants have a tendency to run wild as weeds, they also show whether the plants might be disease-carriers or hosts to harmful insects.

Within some countries, seed for sale is most carefully inspected, and very low limits are set on the kind and number of weed seeds that it may contain.

Cultivation is the time-honored method of keeping weeds in check. In small gardens, the hoe is still the most valuable weed-control tool we have. In large-scale growing, various kinds of cultivators are used. Regardless of the type or frequency of cultivation, it is practically impossible to get rid of all weeds, because seeds remain in the soil, and new seeds are carried in constantly. Cultivation remains, however, one of the most successful means of combating many weeds and the only method of controlling some of them.

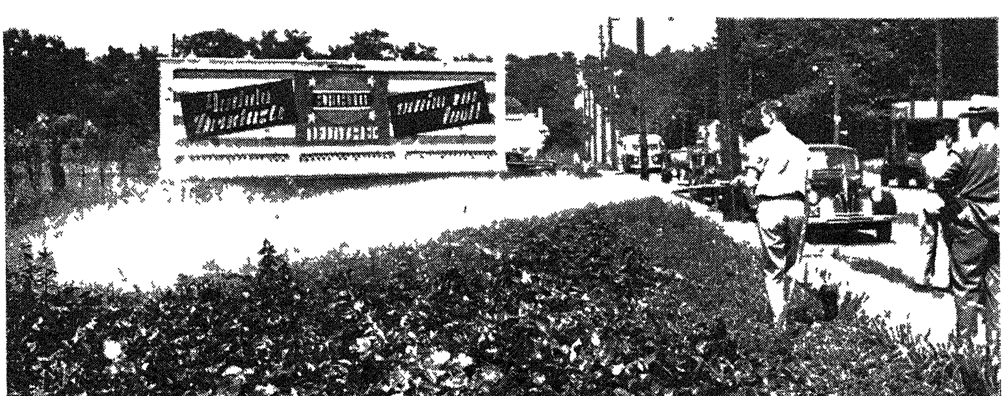
Certain weeds are associated with particular crops and can be kept down by rotation of crops. By sowing a field to small grains one year, a cultivated crop, such as corn, the next year and a hay crop, such as sweet clover, the third year, a good share of the weeds associated with each of these crops can be kept in check. A combination of cultivation and crop rotation is the best general means of control.

Along railroad rights of way, highways and irrigation ditches, weeds are sometimes kept in check by burning or mowing, but this is likely to be only a temporary control.

In pineapple and sugar-cane fields in Hawaii, wide strips of heavy paper are laid and the plants are set out through holes in the paper. The weed seedlings, of course, cannot push through the paper, nor can vagrant seeds blown along by the wind find resting place in the soil. This good device is sometimes used in home and market gardens, but it is pretty costly.

Insects may sometimes be called on for aid. The prickly pear, which overran much valuable land in Australia, was controlled by introducing from South America an insect that tunneled through the plants and killed them. It was necessary, of course, to be sure that the insects used would not attack any valuable plants.

Within the last hundred years or so, there have been many attempts to control weeds by means of chemicals. Some of these have been very successful. However, until around 1940 there were almost no chemicals that would kill weeds without injuring other plants or poisoning animals or birds or doing other harm. Now there are chemicals that are highly selective — that is, they poison certain plants but do not injure other plants or animals. One, known as 2,4-D, has had a great deal of publicity. However, it does kill or injure some cultivated plants as well as weeds, and so it must be used with caution. Weed-killing chemicals will doubtless be more helpful in our fight against weeds, but the man with the hoe is likely to be needed for a long time to come.



Du Pont

A growth of poison ivy in a vacant lot in Wilmington, Delaware, is sprayed with ammonium sulfamate.

THE BUILDER'S MATERIALS

A Survey of the Many Substances Used in Building Construction in Every Age

by
JOHN H. CALLENDER

IN his long career as a builder, man has worked with mud, baked clay, stone, glass, copper, brass, iron, steel, felt, hide, logs, boards, leaves, grass and even snow. Some of these materials he found ready for use; others had to be most carefully prepared before they could serve for dwellings, religious temples, and monuments.

All of the builder's materials, so abundant and so varied, may be divided into three general classes: primitive, traditional and modern. Primitive materials are readily available in nature and require very little preparation; they include logs, saplings, reeds, leaves, grass, skins, clay and snow. We list under traditional materials those that have been in use over a long period of time and that require more or less extensive preparation — stone, brick, tile, mortar, timber, plaster, metal, glass and the like. Modern materials include new or relatively new substances such as structural steel, reinforced concrete, wallboard and plastics.

The names "primitive," "traditional" and "modern" suggest the order in which building materials were first employed by man. They do not stand for definite historical periods, for both primitive and traditional materials are still popular.

We think of a builder nowadays as a specialist who devotes all his time to his chosen lifework. But the history of building with primitive materials generally shows no such specialization.

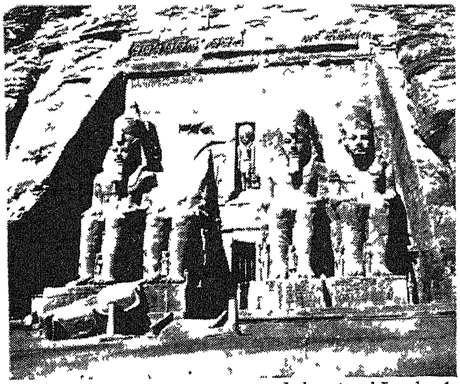
Perhaps an example or two will make this clearer. American colonists frequently came to a land of almost unbroken forest. Before a man could settle anywhere and plant crops, he had to clear away the trees. Many a colonist took the trees that he had cut to make a shelter for himself and his family. Selecting trunks that were straight and uniform in size, he laid one on top of another, notched and lapped the corners and built a log cabin. The spaces between the logs he chinked with clay to make the house watertight, and the log chimney was lined with clay to keep it from burning. The complete house was built by the colonist and his sons, with help from neighbors.

Of course, the American Indians built with primitive materials. The tribes of the

A small log cabin erected by American pioneers.

western plains were hunters, especially of the bison that roamed the plains in enormous herds. Bison and deer meat were the food of these tribes; the skins of the animals were fashioned into clothing. It is not surprising to find that the Plains Indians made their houses of these hides, stretched over a pyramidal frame of saplings.

Primitive materials are generally used in their natural state, without processing; but this is not always true. Many Arabs live in tents of cloth woven from sheep's wool,



Lehnert and Landrock

The massive temple of Rameses II at Abu Simbel, Egypt. It was carved out from the living rock.

goat's wool or camel's hair. In Mongolia, where the herds are mostly short-haired animals, such as cattle and horses, the tents are covered with felted cloth.

Primitive man occasionally built homes of field stone, putting the rocks in place with a minimum of cutting. More often, stone was reserved for temples to the gods or monuments to heroes.

Traditional materials

Stone

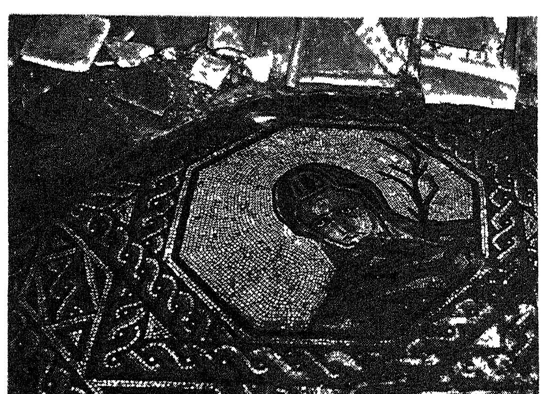
For thousands of years, stone has been without a rival as the material for buildings of a monumental nature — that is, those that are intended to endure and to have dignity and authority. We find the earliest monuments of this sort in ancient Egypt. The Egyptians believed that the earthly body would be needed in the next world, and they invented methods of embalming to preserve the body almost indefinitely. They buried with the body various belongings of the dead person — food, clothing, money, jewelry, cosmetics, musical instruments, books, weapons and toys. The tomb in which the body and all of its possessions were to be buried was built to last "forever."

Nothing seemed more permanent than the stone cliffs that rimmed the Nile Valley; hence, the Egyptians built their tombs of stones cut from these cliffs, or else they carved out tombs in the very cliffs themselves. The tombs withstood the ravages of time and weather and the attacks of all marauding animals except man. As a building material, the stone of Egyptian tombs has proved to be as durable, thus far, as the Egyptians hoped it would be.

Stone provided a material out of which the images of the gods could be carved; it also seemed appropriate for buildings dedicated to these supernatural beings. The kings, who were considered to be gods, came to live in temple-palaces of stone, as did the high priests. This set the style for the wealthy nobility, who also built stone palaces for themselves.

Greece is a rocky country with rich veins of marble; therefore the inhabitants turned naturally to stone for building after wood became scarce. The architecture of the Greeks, executed in white marble, has been an important influence in Western architecture down to the present day.

The Romans built first of brick, but as they came under the influence of Greek culture, they, too, found stone more beautiful. Instead of using solid blocks of stone, as the Greeks and Egyptians had done, the Romans often put up walls of brick, or rubble or concrete, and faced them with thin slabs of stone. For this purpose, they imported rare marbles and porphyries from distant parts of their vast Empire. These stones were selected for their beautiful colors and patterns, and were often cut and laid in such a way that the veining of adjacent stones formed a pattern. Floors were paved with mosaics, made up of small



Pan American World Airways

This ornate pavement of mosaic work was found in the remains of a Roman villa in Bignor, Sussex.

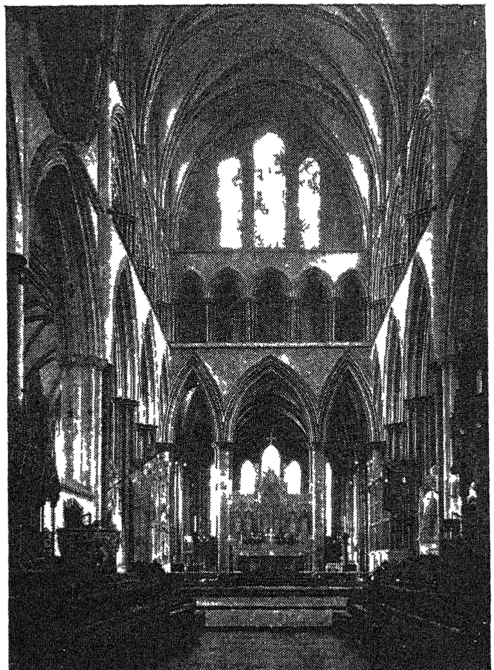
pieces of stone of various colors. These were usually laid so as to provide an abstract pattern; sometimes, however, they formed definite pictures.

One of the disadvantages of stone, from the viewpoint of Egyptian and Greek builders, was the very short distance that a single stone spanned between supports. This made it impossible for them to build a large open room. The interiors of Egyptian and Greek temples give the impression of a forest of columns. The only way in which the span can be increased in an all-masonry building is by the arch; and it is remarkable that the Egyptians and Greeks, master builders as they were, made no use of the arch. The Romans, however, used it extensively in its various forms, especially the vault and the dome, which permitted them to build vast open halls, uncluttered by columns.

In the Middle Ages, stone continued to be an important building material. As medieval civilization moved northward, a new factor was introduced — the desire for more light. The dimness of the interiors of most earlier buildings had been rather a pleasant relief from the brilliant Mediterranean sun. But in northern Europe, light was desirable and man wanted it in his buildings. By the thirteenth century, there had developed in northern France a method of building in which glass took up a good deal of the space formerly occupied by stone in the side walls. Yet far overhead was a solid stone roof. This construction is known as Gothic.

How was it brought about that walls with so much glass could be made to support roofs of heavy stone? The Gothic builder combined arches to form immensely strong vaults, which could be flung up to great heights. He made most liberal use of clerestories — upper stories that were provided with windows lighting up the interior of the building. He provided support for the building by side structures called buttresses.

Thus, he utilized the natural advantages of stone — its strength and its durability — as a building material and he overcame its disadvantages — its heaviness and its inability to span very far. The natural character of stone is massive, inert strength, exemplified by the Egyptian pyramids. But in the late Gothic cathedrals, stone seems to stretch aloft, to soar, in complete disregard of its natural limitations.



British Information Services

The choir of England's Salisbury Cathedral, a splendid example of medieval stone construction

A well-built, solid stone building is as durable a structure as man has ever devised. The forces of nature are rarely able to injure it seriously; masonry buildings have successfully withstood hurricanes, tidal waves, long submersion under water and burial by sand dunes and by volcanic ash. Only a severe earthquake or a major landslide, among natural forces, would be likely to destroy them.

But man can easily raze the sturdiest stone buildings. High explosives, in time of war, have destroyed in a few seconds structures that had stood for thousands of years. In time of peace, too, man has deliberately dismantled buildings, stone by stone, to make way for something else or to get the stone for another building. Most of the picturesque ruins of Rome, such as the Colosseum, are ruins because medieval builders made quarries of them.

In spite of today's wealth of new mate-

rials and new techniques of building, stone still seems to be considered the noblest material. Our principal public buildings — cathedrals, railroad stations, museums, libraries and other buildings that are intended to be impressive — are faced with stone, regardless of their construction.

Most desirable are the even-grained stones that are fairly easy to cut, such as sandstone, limestone and marble. If too soft, the stone will probably not be very durable. Some coral limestones can be cut with a knife, but, unless they are stuccoed, they weather very badly. Granite, which is stronger and more durable than limestone but harder to cut, is excellent for foundations and for whole buildings — also for curbstones and paving blocks. In rubble, or roughwork, masonry, as distinguished from ashlar (cut stone), practically any type of stone may be seen. Slate, which splits easily in one plane, makes good flagging and roofing.

Ashlar masonry is usually set in mortar, although the Greeks and the Incas and some other fine masons used none. The purpose of mortar is not to hold the stones together (metal dowels provide for that) but to give a small space between the stones, to allow for minor errors in cutting and to waterproof the joints.

The exposed face of stone masonry may be given various textures, ranging from highly polished to extremely rough, or rock face. Or it may be carved into various designs. The joints may be recessed in such a way as to form a series of channels in the outer surface of a wall. A rugged effect, called rustication, is produced.

Brick and Tile

Second only to stone as a permanent building material and second only to wood as a utilitarian material is brick. It is made of clay, molded into blocks while moist and then hardened in the sun or by fire. Standing midway between wood and stone in cost, brick has been used as a substitute for either or both of these materials in places where they were not available.

The first bricks were hardened by being exposed to the sun. At about the same time that the Egyptians were first learning to cut stone into blocks and build with it, the people in Mesopotamia discovered that if bricks were baked in an oven, instead of merely being dried in the sun, they would be much harder and more durable. Entire cities were then built of brick, from the most imposing temples and palaces down to the least important buildings.

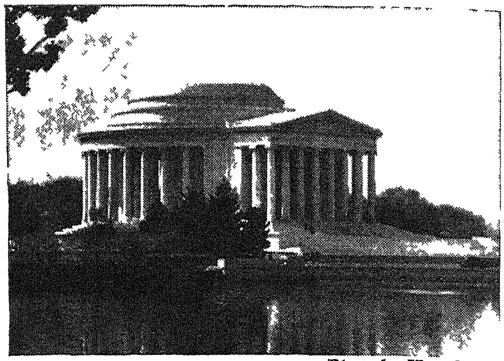


Photo by Horydozak

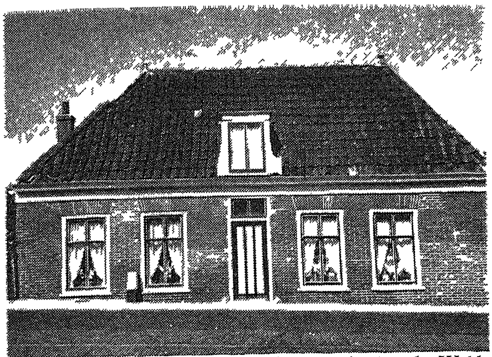
A marble masterpiece: the Thomas Jefferson Memorial, erected in Washington, D C, in 1941.

Brick is perhaps not quite so enduring as stone, but it will last well over a thousand years, which should be durable enough for most purposes. Furthermore, it is fireproof, which wood is not; hence, it is replacing wood in many areas.

Bricks are always laid in mortar. The type of mortar, the width of the joint and the skill with which the work is done all have an important effect upon the appearance, the durability and the waterproof qualities of a brick wall.

A wall consists of at least two thicknesses of brick. In order to tie these two thicknesses together, some of the bricks are turned so that their length extends back into the wall, and only their ends are exposed. These headers, as they are called, may be arranged to form a pattern, which can be quite decorative. The Dutch and Flemish, who are very skillful builders in brick, have developed patterned brickwork to a high point.

In modern times, brick walls are sometimes built with a more or less continuous hollow space between the two thicknesses. This gives better insulation and prevents water from coming through. In this case,



Standard Oil Co. (N. J.) photo by Webb

The patterned brickwork of this small house at Lisse, Holland, produces a most pleasing effect

the two brick walls are tied together, not by headers but by metal ties built into the brickwork.

Brick varies in color, according to the clay; pigments are rarely introduced. Although most bricks are brownish red, they range from deep maroon to light pink and are occasionally in such colors as yellow, buff, gray or dark brown. Face bricks of extra hardness and having special colors and surface textures are sometimes used for the outside of the wall, the remainder of the wall being common brick.

In order to span even a small opening in brick masonry, an arch must be built, or else a lintel (beam) of some other material must be used. The Babylonians, who had no other materials, used the arch extensively. In other countries, stone lintels were often used over small openings, such as windows and doors, and, in more recent times, iron and steel have served the same purpose. But, as in all masonry construction, long spans require the arch in some form.

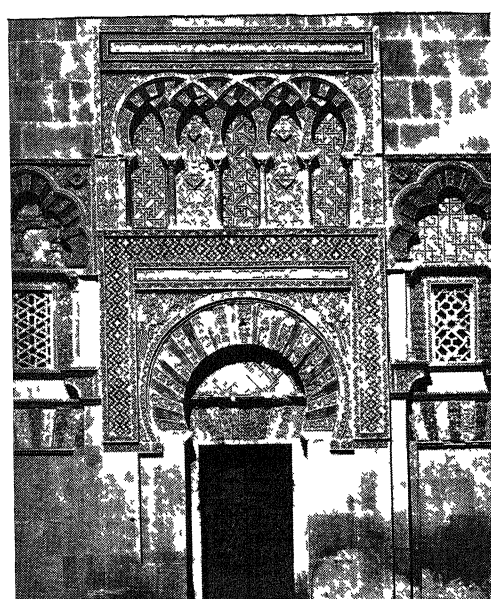
The Babylonians discovered that, if certain minerals and pigments were added to the surface of clay, they would melt during the firing and form a hard, smooth, glazed surface. These glazed bricks were used decoratively to relieve the monotony of unbroken brick masonry. Glazed clay, generally in thin, flat shapes, called tiles, later became an important building material. Tile has been used for decoration by most people who have built extensively in brick — the north Italians and the Dutch, for example. But it was the medieval Mohammedans who carried tile to its highest point of development, especially in Persia and in Spain. There, entire buildings, inside and out, were faced with tile in a thrilling variety of patterns and colors.

Burned clay (terra cotta) has served from ancient times and still serves for roofing tiles and drainage pipes. Hollow building blocks of terra cotta have been much used in modern times for fireproof partitions and walls that do not bear loads. Special firebrick is made for lining the fireboxes of boilers and for other industrial structures where very high temperatures prevail. An extremely hard type of brick is made especially for paving streets.

Wood

Wood is the world's great utilitarian building material. Probably there are more buildings of wood today than of any other substance that is used for building purposes; more space is enclosed by wood than by any other building material.

Wood is in some respects ideal for building purposes. It is still plentiful in many parts of the world and could be grown as



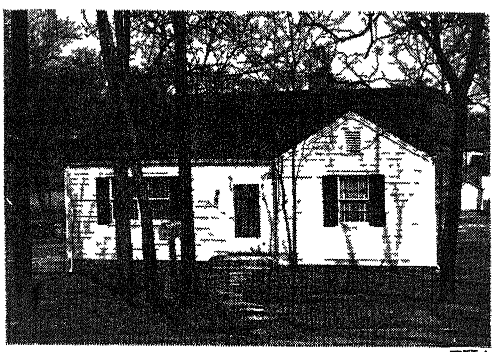
Ewing Galloway

Intricate tile patterns adorn the façade of the Great Mosque in the city of Córdoba, in Spain.

a crop in most other places. Unlike the masonry materials we have been discussing, it is light but very strong for its weight. It is easily worked, is a good insulator, is warm to the touch and springy to the step. It also has certain disadvantages. It is inflammable; it is apt to decay; it shrinks or swells with changes in moisture.

In wood, moderately long spans are easily provided and extremely long spans are quite practical, with the aid of trussing, or bracing. Many medieval buildings with masonry walls had wood roofs. In a few parts of the world, notably Scandinavia and Japan, wood has been used throughout, even for the most monumental buildings.

Wood is America's traditional house-building material. One authority estimates that even today almost 90 per cent of the American people live in wooden houses. Formerly, wood construction in both Europe and America was in the form of heavy timbers, hand-hewn and joined together without nails. In the nineteenth century, a new type of construction was introduced into the United States. Slender two-inch by four-inch pieces of lumber formed the uprights of a wall; they were spaced fairly close together and tied, braced and stiffened by a continuous sheathing of one-inch boards nailed to the outside. Houses constructed thus were light, and they could be put up rapidly. This method of building, called frame construction, was regarded at first as an emergency measure for temporary building; today, with certain modifications, it is a standard practice in the United States



FHA

Small frame house, in Nashville, Tennessee. Frame construction is popular in the United States.

The softwoods make up by far the greater part of our building lumber. "Softwood" is a technical term for lumber from any coniferous, or cone-bearing, tree, regardless of its hardness; some softwoods, such as long-leaf yellow pine, are much harder than some hardwoods like poplar or basswood

The framework of the house is most often of Douglas fir, yellow pine, spruce, hemlock or balsam fir. The boards forming the outer surface may be white pine, redwood, cedar or cypress; sometimes yellow pine, ponderosa pine, Douglas fir or hemlock are used.

Millwork (windows, doors, their frames and all kinds of decorative moldings) is usually made of a soft, even-textured wood, with little noticeable grains: white pine, sugar pine and ponderosa pine are most popular. Doors are often made of Douglas fir or of hardwood — birch, gum, maple, oak or walnut. Flooring is almost always hardwood, usually oak, sometimes maple; occasionally it is of yellow pine or Douglas fir. Oak, walnut, mahogany, teak and many other domestic and imported hardwoods provide interior wood paneling in the more luxurious types of buildings.

Plaster and Stucco

Plaster is of ancient origin and has been used all over the world, especially for interiors. A wall may be built with considerable roughness and inequality and with no consideration for appearance if it is later to be plastered. A plastered wall or ceiling can be made to produce an unbroken, smooth white surface, which cannot be achieved by any other means. Plaster may be given various surface textures, or it may be molded or colored, as it is applied.

Elaborately molded plaster ceilings were a feature of English Renaissance mansions. Most of the extravagant ornament of the Italian and Spanish baroque periods was molded of plaster, and such molding was prominent later in the Georgian style of architecture in England. Mural paintings done on wet plaster are known as frescoes, and their beauty, as well as their durability,


Los Angeles Chamber of Commerce

The Mission San Fernando, in Los Angeles, California, is an example of fine stucco construction.

may be seen in the examples uncovered at Pompeii and in Crete.

Interior plaster has generally consisted of sand and lime, with some fiber or hair to give it additional cohesion. Gypsum often takes the place of lime, or it may be added to the mixture. Exterior plaster, usually called stucco, must be more waterproof and more resistant to freezing and thawing than interior plaster. Stucco consists of cement and sand with a small amount of lime. It was exceedingly popular in the Italian Renaissance; it has been widely applied to buildings in many lands to cover rubble masonry or poor brickwork.

There are many familiar examples of stucco work in the United States, in the Pennsylvania "Dutch" area and in the Spanish missions of the southwest. Most Latin American buildings of the colonial period are of this type. Many modern suburban dwellings are of stucco or of half-stucco. In Italy and other Mediterranean lands, beautiful effects are produced by colored stucco: reds, pinks, blues, greens and grays are popular.

Plaster may be applied directly to masonry, but in wood construction it must be applied to laths or some other special material to which it will adhere. Laths are thin strips of wood, spaced slightly apart so that the plaster can fill the space between and bulge out behind and thus be keyed securely in place. Wood laths of this type are disappearing, for it takes too long to nail each lath separately in place. Materials to hold the plaster now include expanded metal, welded wire, gypsum board and insulating board.

Hollow blocks of gypsum make good fireproof partitions and other non-load-bearing walls. The plaster is applied directly to these gypsum blocks.

Metal

Until modern times, metal was not a primary building material; but it has long served in connection with other materials. Copper and tin were the most abundant metals of ancient times. Bronze, a mixture of these two metals, was sometimes concealed in stone masonry to key the stones together; sometimes it was exposed. Doors, windows, grilles, railings, hardware, lighting fixtures, fountains and even bathtubs were made of bronze by the Greeks and Romans. Except for bathtubs, bronze is still used for these purposes, by those who can afford it, because it is a strong, handsome metal that does not corrode.

Copper, which can be pounded into thin sheets, has long served for roofing, gutters and downspouts. It has also provided flashing — waterproofing material used to seal a joint in the roof or between the roof and another part of the building. Copper makes fine water piping, for, like bronze, it corrodes but slightly. After years of exposure, it acquires a light, bluish green coating known as a patina.

Lead is another metal with a long and honorable history as a building material. Since ancient times it has been used for roofing, flashing, gutters, downspouts and water piping. (Our word "plumbing" comes from *plumbum,* the Latin word for lead.) It is an important ingredient in the manufacture of paint, glass and ceramic tile. Tin is another noncorroding metal of ancient lineage. Tin roofing and flashing, tin coating on steel sheets, solder (a lead-tin mixture that is part of the plumber's stock in trade) — these are some of the forms in which tin appears in building.

Zinc's most important use today is for coating steel, or galvanizing, as it is called. It is also an important ingredient in the

manufacture of paint and wood preservatives. Zinc roofing, flashing and weather stripping are not uncommon.

Brass, a mixture of copper and zinc, serves principally for water piping, door hardware and lighting fixtures. It varies in color, depending upon the proportion of its ingredients, from nearly white to orange-red. Most brass is more or less like gold in color; if kept polished, it is attractive.

Iron and its derivative, steel, are so important in our modern civilization that we often call this the Iron Age. Yet they were not essential building materials until about 1850, though from ancient times iron has been important for tools, weapons and armor. In the Middle Ages, wrought iron was widely popular for door hardware, lighting fixtures, railings, grilles, dungeon bars, drawbridge chains and spikes and bolts in wood trusses.

These uses continued with little basic change down to the nineteenth century. In the Renaissance, especially in Spain and Italy, wrought-iron grillwork was developed to a fine art. Iron occasionally reinforced masonry, as in the case of the chains that were put around the base of the great dome of St. Peter's and other Renaissance domes. Wrought iron, hand-forged by skilled blacksmiths, was the only form in which iron had a place in construction until comparatively modern times.

Glass

Glass has been used for windows since Roman times, but not until the late Middle Ages did it become a major item in building. Then, in northern Europe and England, not only the great cathedrals but also royal palaces, town halls, city houses and other types of buildings were opened up with huge expanses of glazed windows. Medieval glass was in small pieces, only a few inches in each dimension. These were set in lead cames — that is, grooved bars of lead that formed a resilient and watertight frame for the precious little "lights," as the small pieces of glass were appropriately called. The glass was hand-blown and quite irregular in surface, texture and color; but it let light in. The people of northern Europe loved it so much that in their cathedrals they installed magnificent stained-glass windows, which glowed like jewels.

In the Renaissance, this brave expanse of glass gave way to the small windows of the classical styles, which had originated in the Mediterranean region, where windows were not very important. Then builders discovered the charm of glass as a material for interior decoration. They lined walls with mirrors — the wonderful Hall of Mirrors in the Palace at Versailles is literally a shining example. Small pieces of crystal cut in prisms and hung on chandeliers reflected and diffused candlelight.

Modern materials

Toward the middle of the nineteenth century, building began to feel the effects of the Industrial Revolution. Much work that had been done by hand could be done more cheaply by mass production in factories, and, as labor costs increased, it was necessary to find short cuts in building techniques. New materials were introduced; the most important were steel, reinforced concrete, insulation and sheet materials.

Iron and Steel

The first iron bridges were built in England in the 1840's. As early as 1851 the Crystal Palace, originally set up in Hyde Park, in London, was built entirely of iron and glass. Wrought iron and cast iron began to be used for columns and, occasionally, for girders and beams. In 1889, Gustave Eiffel made the world gasp by building an iron tower in Paris to the dizzy height of almost a thousand feet.

It was in Chicago in the 1880's that the complete steel frame was first used. The steel frame is a continuous cagework of steel columns and beams that forms the skeleton of a building and upon which everything else is hung. The walls do not bear the weight of the building; hence they can be quite thin and of almost any material. Windows can be as large as desired; in fact, the entire wall can be a window.

In steel-frame construction it is almost as easy to build vertically as horizontally.

As soon as the invention of the elevator made skyscrapers practical, man began to build them enthusiastically.

Steel is the form of iron most useful as a building material. It differs from cast iron in that it is not brittle, but malleable — that is, it can be shaped by hammering or pressing or rolling. Wrought iron is also malleable, but cannot be manufactured by mass production. It is, therefore, more expensive, less plentiful and less uniform in quality than steel.

Steel can withstand both compression and stretching; in this respect it may be compared to wood. Long spans are easy in steel construction. Buildings of this material look strikingly different from masonry buildings unless, as is often the case, they have been disguised to resemble masonry buildings.

Steel has two great enemies, fire and corrosion. Although steel does not burn, it loses its strength very rapidly in even a small fire. For protection from both fire and rust, the steel frame is surrounded by at least two inches of fireproof material, most often of concrete, but sometimes of brick, stone, terra cotta or gypsum.

Steel is used for many other building purposes: doors, windows, stairs, decking, roofing, gutters, siding, lath, hardware, plumbing, heating and most other mechanical-equipment items. Cast iron serves for boilers and radiators, as well as for plumbing fixtures and drainpipes.

Reinforced Concrete

Concrete was employed extensively by the Romans and can thus hardly be called a modern material. But when it was discovered in the late nineteenth century that concrete can be reinforced with steel rods, an entirely new type of material was born, unlike anything that had ever been known in building before. Concrete is as durable as any material known to man, and it is capable of supporting enormous loads. It therefore serves for heavy construction — dams, piers, docks, roads, foundations, warehouses and the like. But when reinforced with steel, it can be used, like steel, for long spans and light construction. In

Standard Oil Co. (N. J.)

A lofty iron structure: the Eiffel Tower, Paris.

Europe, where structural steel has not been so plentiful or cheap as in America, reinforced concrete may be seen in almost every conceivable type of building.

Concrete, like stone and brick, can stand very high compression but cannot withstand stretching; in other words, it has very high compressive strength and very little tensile strength. But if we embed a steel rod near the bottom of a concrete beam, the steel, which has high tensile strength, will carry the load and thus keep the concrete from cracking. The concrete, in turn, protects the steel from fire and rust. This same principle applies in reinforced brick masonry, the steel rods being placed in the mortar joints or run through holes in the brick.

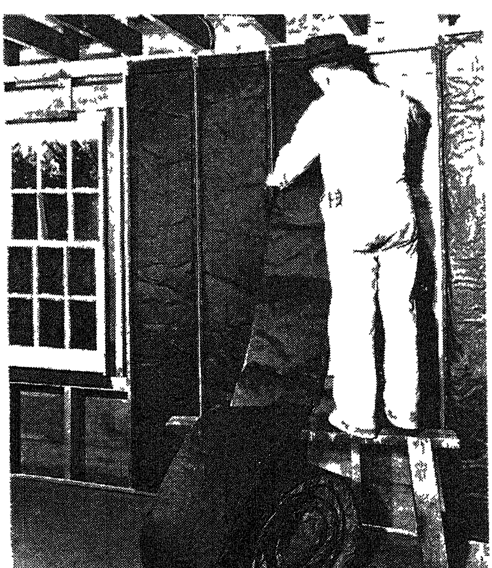
Concrete is made of portland cement, sand and broken stone or gravel. Portland cement is simply a modern refinement of the various natural cements known to the Romans and later builders. It is made by burning certain limestones and shales together in the right proportions and at a very high temperature.

One of the advantages of concrete is that it is monolithic — it forms a single block.

It can be poured into forms, and it hardens in place so that the whole structure is like one massive stone; there are no joints to worry about. But this is also a disadvantage, since it requires an enormous amount of material and labor to make the forms into which the concrete is poured; besides, a good deal of valuable time is lost waiting for the poured concrete to harden. However, there are now new types of concrete that develop high strengths very quickly and permit the forms to be removed within twenty-four hours after pouring.

Another approach to the solution of this problem is to precast the concrete into blocks or slabs before they are placed in the building. These precast units resemble masonry rather than monolithic concrete. Hollow blocks of concrete are now very widely used as masonry in small buildings. Where appearance is a factor, they are usually stuccoed. Precast joists (beams) and slabs serve for floors and roofs, usually in buildings with masonry walls. Precast wall slabs are among the prefabricated home-building devices.

The difficulty with large precast concrete units is their great weight, which makes shipping and handling very expensive.



Armstrong

Insulating a room with insulating wool in roll blankets. The "wool" is made of fine glass fibers.

Therefore, a great deal of experimental work has been done in an effort to produce lightweight concrete. In one method, the stone in concrete has been replaced by lighter materials such as cinders, slag or vermiculite, a form of mica. Another method consists of omitting the stone entirely and causing the cement and sand to foam like whipped cream before the set. In both cases, the result is lighter weight and better insulation, at the cost of reduced strength and waterproofing qualities. The strength may be greatly improved by introducing wood or straw fibers.

Insulating Materials

When man began to heat his buildings, he found that heat was expensive, and so he began to develop insulating materials that would conserve the heat. These were applied first to the heater itself and to the pipes or ducts that led from it, in order to prevent the loss of heat before it was delivered at the place where it was wanted. Then the walls and roofs of buildings were insulated, so that the heat could not escape easily to the outdoors.

Boilers are insulated by means of two remarkable minerals — asbestos and diatomaceous earth. Asbestos is a rock that is fibrous, like cotton or wool, and the fibers can be woven into cloth or made into paper Diatomaceous earth is a lightweight limestone formed by the skeletons of countless millions of microscopic plants, called diatoms, that lived in the sea ages ago. These materials are mixed with enough cement to bind them together and are then plastered to the boiler. For pipe insulation, asbestos is mixed with another lightweight mineral, magnesia, usually in preformed sections, which are held in place by metal bands.

Insulating the walls and roof of a building is very much like insulating our bodies by the clothes we wear or the blankets under which we sleep. One popular type of insulaticn is a sort of "quilt" made up of some woollike or cottonlike material between two pieces of very tough building paper. The stuffing may be made from rock, slag, wood or bark, which has been processed into a fibrous, woolly material, or

from a natural material of this type, such as eel grass, kapok or cotton. Occasionally, the filling material in loose form is simply poured into the hollow spaces in the wall. The filler is sometimes of the mineral known as vermiculite; it comes in grains and looks much like a breakfast cereal.

Another type of insulating material does double duty. It is made in the form of a building board and can take the place of wood sheathing or lath or both lath and plaster. These insulating boards are of vegetable fiber, derived from wood, sugarcane, straw and the like. One board is made from old newspapers; it is just as good as the others, and perhaps even better!

The best insulation is a vacuum; the next best is air, provided it does not move freely. All of the insulations that we have mentioned above trap thousands of little pockets of dead air, which, since they cannot move, act as excellent insulators. An insulation that works on an entirely different principle is aluminum foil, which reflects the heat waves in exactly the same way that a mirror reflects light waves.

The weather stripping of windows and doors

A great deal of heat is lost through windows and doors, most of it through the cracks around the edges. Weather stripping is applied to stop this loss. Interlocking metal strips are the ordinary form of weather stripping, but felt or rubber gaskets are not uncommon. Heat loss through the glass itself can be reduced only by adding another piece of glass to form an insulating air space between. This is usually done in the form of a storm sash. There has recently been developed a double glass, with the air space between permanently sealed. It can be installed in any ordinary sash just like a single piece of glass. Plastic is also used for insulation purposes.

Refrigerators and cold-storage rooms must be heavily insulated, and they have a special problem of moisture condensation to contend with. In cases like these, natural cork, pressed into blocks, provides insulation. Foamed glass and foamed rubber have been developed for this purpose, and foamed plastics have also been tried.

Sheet Materials

With the thin, sheetlike materials known as wallboards, large areas of wall or ceiling can be covered very quickly, and the wall can be painted immediately afterward. About the only disadvantage of the sheet material is that the joints are sometimes unsightly. Some efforts have been made to conceal the joints in order to make the material resemble a plaster wall. It is now becoming more customary to give the joints a V-shape and expose them frankly. Most wallboards are for interiors only, but some waterproof types have been developed for the exterior of buildings. In this case, the joints are a practical as well as an aesthetic problem; they must be made weathertight, and this is not always easy.

The first wallboards were made of very heavy cardboard. Next came plaster board, an early sandwich-type board consisting of a thin core of gypsum with faces of heavy paper. Then came the fiber, insulating boards mentioned above. Another type, known as hardboard, is thin and smooth, and, as the name implies, very hard. It may be made of wood fiber compressed under very heavy pressure, or of asbestos and cement or of paper impregnated with a synthetic resin. All of these materials may be obtained already decorated, which saves another step in finishing the building. Some of the hardboards have an enamel finish of synthetic resin resembling the glaze of tile; in fact, they may be marked off into squares to imitate tile.

Plywood is a sheet material made up of three or more thin sheets of wood, called veneers, glued together with the grain of each sheet at right angles to that of the adjacent sheet. Since the strength of wood is much higher and its shrinkage is much lower along the grain than across the grain, plywood produces a stable board that is strong in any direction.

Plywood is not a new invention by any means; furniture of this material was made by the ancient Egyptians and by the fine cabinetmakers of eighteenth-century France

and England. But as a building material, plywood was just another wallboard until the middle of the 1930's, when waterproof plywood was developed by using synthetic resin adhesives in a hot press. This made plywood a dependable, weatherproof building material that could be applied indoors or out, structurally or decoratively. It is very important for building purposes.

Most plywood is made of Douglas fir. For decorative effect, plywood can be faced with practically any known wood, including many rare and beautiful imported ones. This has resulted in an increasing use of natural wood as an interior finish, in place of paint or wallpaper.

Two weatherproof sheet materials that have long served for exterior walls and roofs of factories and other utilitarian buildings are corrugated steel and corrugated asbestos-cement board. These thin materials have sufficient stiffness to span several feet between supports and are thus an economical method of enclosing a frame structure.

The development of sheet materials and waterproof adhesives has encouraged a more efficient use of materials in the structural engineering sense. Now we can attach a finishing material to the frame in such a way that both act together as one, and the finishing material actually carries a considerable part of the load. This type of construction is known as stressed-skin. Prefabricated stressed-skin panels are usually of plywood, though they may be of steel, aluminum or fiber board. The hollow spaces in the panels are filled with some insulating material, such as glass wool.

The sandwich-type panel represents an even more advanced step. Imagine a stressed-skin panel of the type we have just described, but with a rigid insulation, like corkboard, instead of glass wool. The faces may then be glued directly to the insulation, and the framing members may be omitted entirely. One material of this type, having a core of fiber insulating board and faces of asbestos-cement board, has been on the market for many years.

During World War II, great advances were made in the development of this type of panel for aircraft construction, and many lightweight panels of amazing strength resulted. The airplane manufacturers first used a core of balsa wood with faces of aluminum. Later, they tried foamed plastic cores, and finally honeycombs of paper impregnated with synthetic resin.

Other Modern Materials

Asphalt served the ancient Babylonians for calking and waterproofing, but modern man has given it many more jobs to do. We all know it in paving and in roofing. The commonest modern roofing material is a felt made of paper and asbestos and impregnated with asphalt. For flat roofs, this felt is applied to the roof in successive layers with hot asphalt mopped between each layer. For sloping roofs, the felt is cut into strips to resemble shingles and is applied like shingles. Asphalt is also pressed into tiles for flooring; coloring matter is added and a number of attractive designs are available.

Linoleum is a resilient, sheet flooring material made of linseed oil and ground cork. It is gaining steadily in popularity, since it gives an attractive and durable floor that has no cracks and is easy to clean. Other modern flooring materials are rubber, cork and plastic.

A number of modern materials will probably become increasingly important in building in the near future. Plastics (synthetic resins) in the form of adhesives and coatings are already very popular, as we have pointed out. In solid form, they have long been used for electrical switch plates and other small gadgets. Aluminum, more plentiful and cheaper as a result of the war, is beginning to serve for roofing, flashing and siding as well as for decorative purposes, and, in the form of foil, for insulation. Stainless steel, also popular as a decorative metal, will doubtless soon find a wider scope.

Scientific research in building materials is neither well organized nor adequately financed; nevertheless, it does go on, and it has already produced gratifying results. To an ever greater extent, the research man is creating new materials to solve the specific problems of the builder.

THE STRATOSPHERE AND THE KENNELLY-HEAVISIDE LAYER

by

ROLAND LLOYD ROY

B.S. in E.E. and M.S.

As the scope of man's knowledge expands there is a continual acquisition by the practical world, the world of the layman, of certain theories and terms which formerly were to be found only in the notebooks of the scientist. In the process of this acquisition there is always a transition period when, although in fairly common use, such terms and theories are only vaguely understood by the non-scientific individual. Two such terms which have recently made their appearance in literature of a general nature are "stratosphere" and "Heaviside layer". As both of them refer to certain regions of the earth's upper atmosphere this chapter will attempt to clarify their meanings together.

The very great effect which the weather has always exerted upon the life of man must have focused his attention upon the region above him at an early date in history. Despite the fact that the science of meteorology has had a long period of development, it has only been in the last fifty years that much of the knowledge which we now possess of the gaseous portion of our sphere has been accumulated.

Until almost the end of the nineteenth century meteorological observations had been confined to the lower altitudes and the conditions in the upper regions of the atmosphere could only be surmised. By means of sounding and passenger carrying balloons, observations had been made up to a height of 2 or 3 miles and had shown that conditions were very variable both with regard to air currents and temperature up to a height of about 3,000 meters above the earth's surface. Above that point the changes became much more uniform, with the temperature decreasing about 6° C. per 1,000 meter rise and the winds, although still slightly affected by surface conditions, becoming generally easterly in direction and much stronger. On the strength of this knowledge it was assumed by many scientists that this condition of decreasing temperature and increasing wind velocity would continue until the outermost portions of the atmosphere were reached.

This supposition was rudely upset in 1898 by Teisserenc de Bort, a meteorologist at Trappes, France. By means of sounding balloons, de Bort obtained observations at much higher altitudes than previously had been obtained. His results were consistent with former observations up to a height of about 11 kilometers above sea-level. Above that point, however, a remarkable change took place. Instead of the temperature continuing to decrease at the normal rate of 6° C. per kilometer as it had below, it remained constant or even increased with further increase in altitude. The first name applied to this newly discovered region of the atmosphere was "isothermal layer" in view of its nearly constant temperature. This was later supplanted, however, by the one which it now bears, "stratosphere".

OFF FOR THE STRATOSPHERE

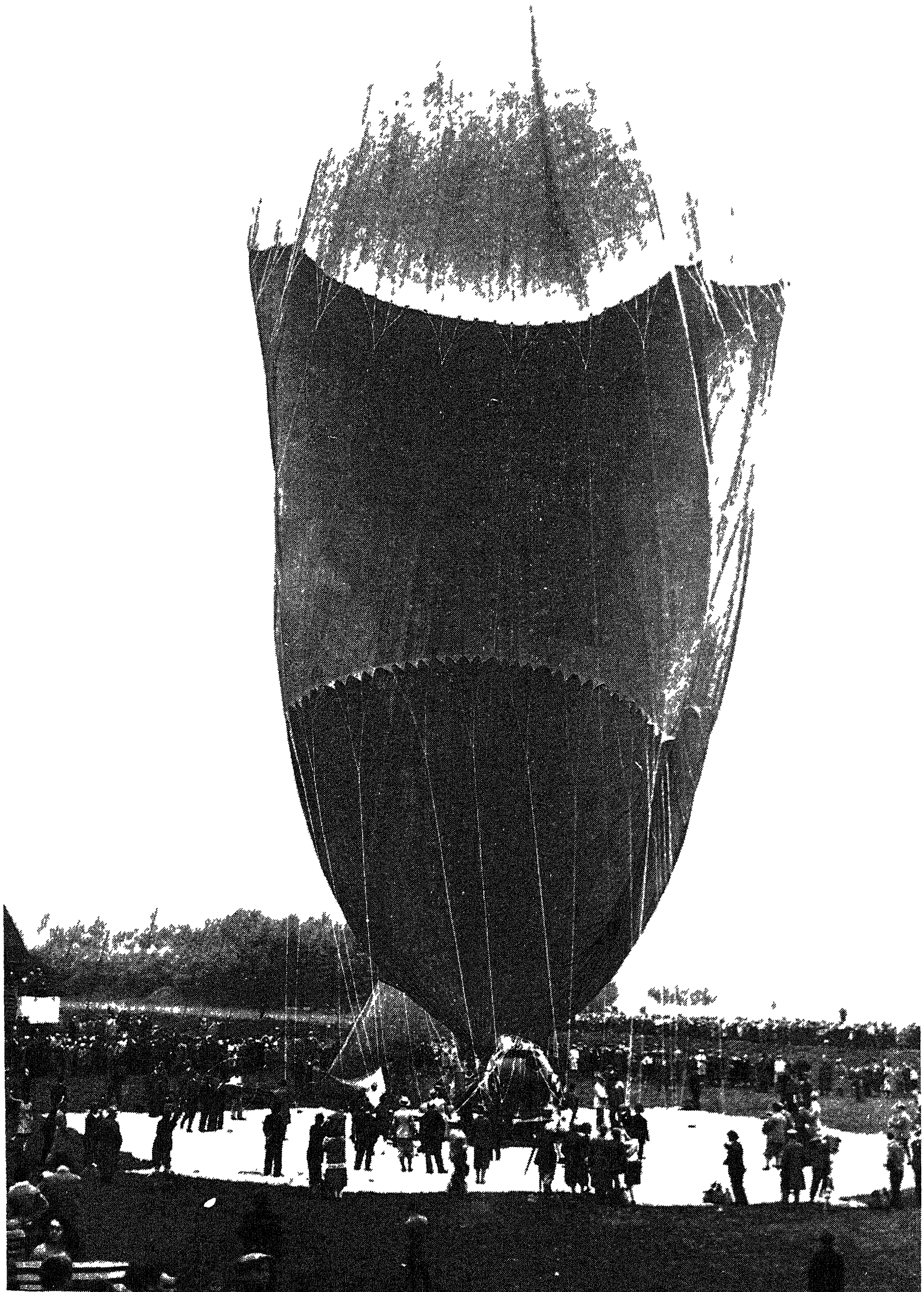


Photo from Wide World Photos

THE BALLOON, WITH GONDOLA ATTACHED, WHICH LIFTED PROF PICCARD HIGHER THAN ANY MAN HAD PRECEDED HIM.

The experimental work of de Bort has been confirmed and further advanced by a number of scientists since 1898 among whom Humphreys, Gold, and Milne have been particularly active. An interesting man-carrying balloon ascension into the stratosphere was made in the summer of 1931 by a Belgian professor, Auguste Piccard, which served to focus public attention upon this newly discovered region The research carried on by these men resulted in a new era in the development of meteorology as it was necessary to revise, more or less completely, the existing theories regarding the atmosphere in order to explain this new phenomenon.

The most distinguishing feature of the stratosphere is its temperature. This factor varies with the conditions existing at the surface of the earth and, therefore, with season, latitude, surface altitude, and barometric pressure. The average temperature at the lower edge (See Fig. 1) is about —55° C. in the middle latitudes. As further ascension is made a slight increase in temperature is usually found although at times a constant temperature prevails

The height of the lower boundary of the stratosphere is variable, being affected by the same factors as its temperature. The average altitude at which this layer is penetrated is about 11 kilometers above sea-level Just how high this approximately isothermal condition exists is unknown. Its presence has been verified by sounding balloon observations to an altitude of 40 kilometers Conditions existing above that point are a matter of conjecture but it is generally believed that the temperature again begins to decrease above a surface 40 or 50 miles high.

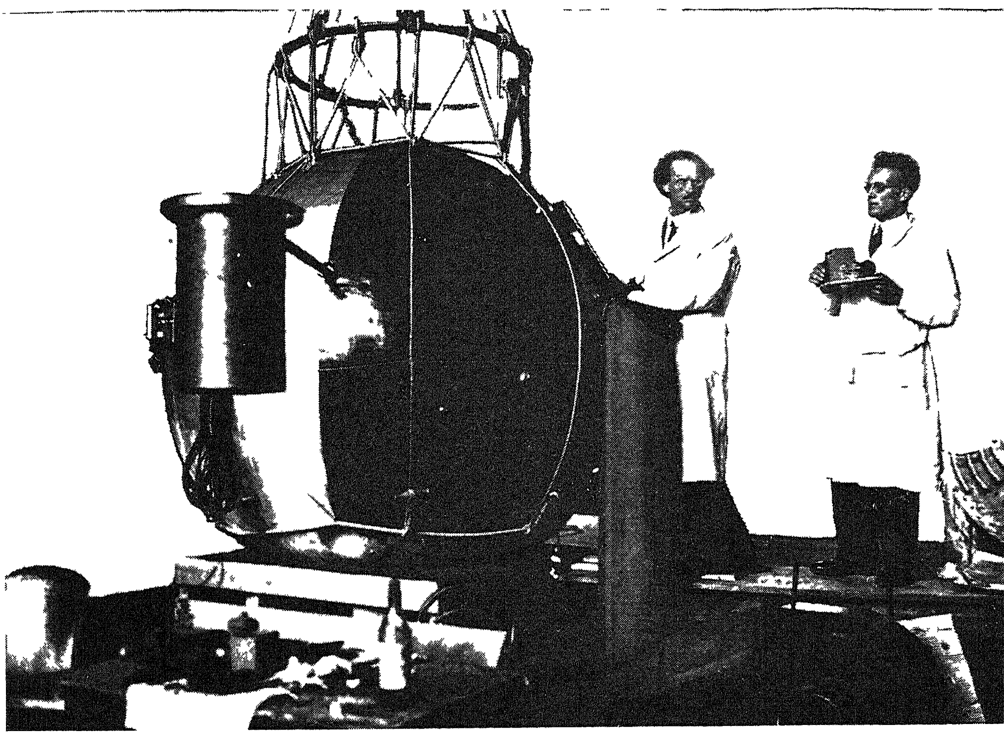


Photo from Wide World Photos

PROF PICCARD (LEFT) BESIDE THE ALUMINUM GONDOLA.

Other interesting characteristics of the stratosphere are its freedom from storms and clouds and its very moderate winds. The essential requirement for an atmosphere of storms, clouds, and variable winds is that moisture and convection currents (rising currents of warm air and descending currents of cold air) be present.

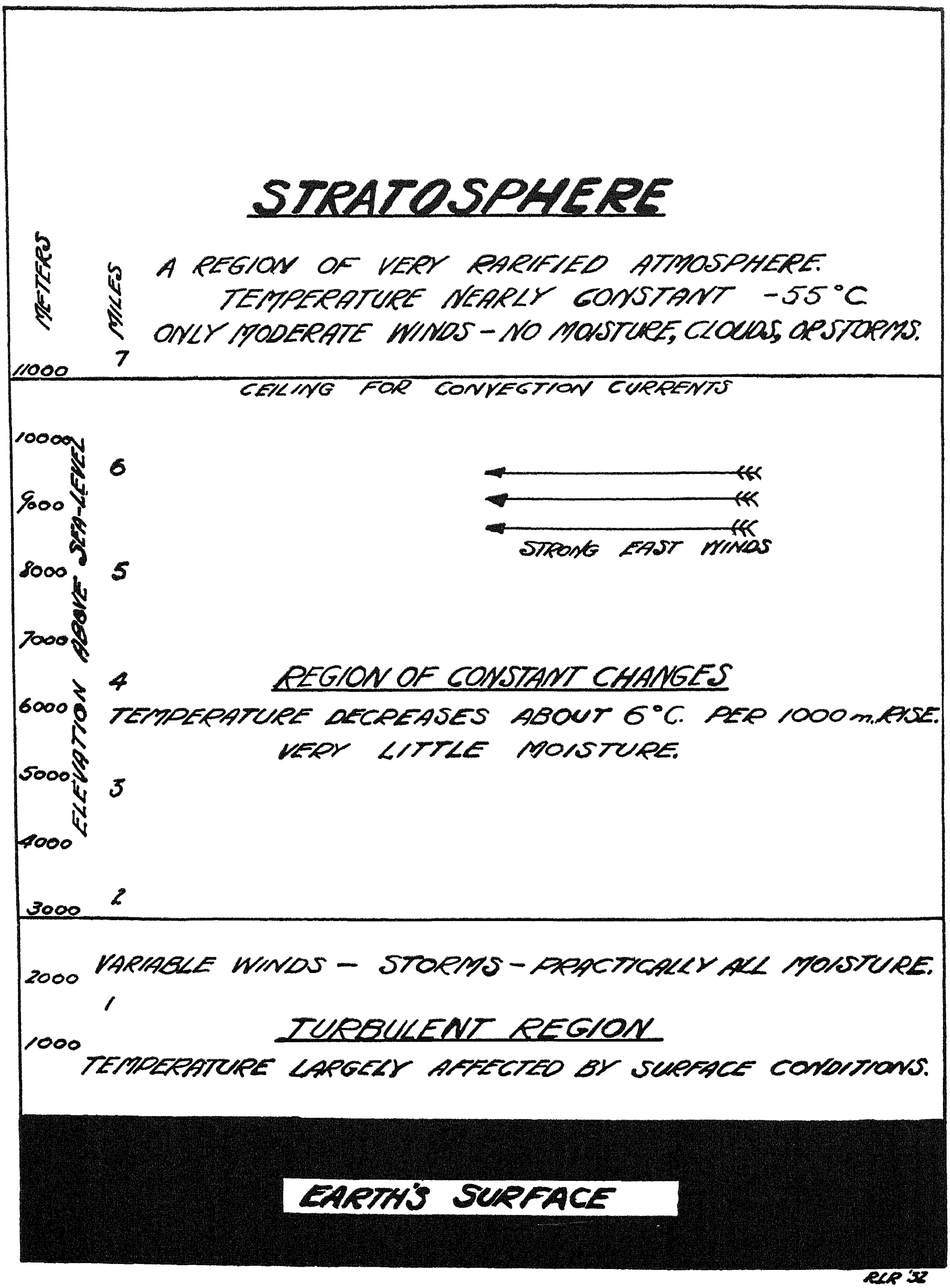


FIG. I. THE REGIONS OF THE ATMOSPHERE.

Practically all of the water vapor is concentrated in the region below 11 kilometers altitude and it is impossible to have convection currents in an atmosphere of constant temperature. The absence of these two factors causes the

stratosphere to be a region of clear, rarified atmosphere; free of all the moisture and turbulence found close to the earth's surface. It might be thought that the planetary circulation, which causes strong easterly winds between the altitudes of 3 and 11 kilometers, would exist in the isothermal region also but observations there have revealed only mild currents.

The generally accepted theory regarding the stratosphere was independently brought forth by Humphreys in America and Gold in England. Their explanation is based upon the thermodynamic principles involved in the transfer of heat from the earth to space.

By far the greater portion of the energy which is received by the earth comes from the sun in the form of radiant energy or light. Approximately 50% of this energy is lost, mainly by the reflection of, and to a slight extent by the absorption of, the atmosphere. The remaining 50%, however, reaches the surface of the earth and is there converted into heat. It is a fundamental law of thermodynamics that if a body remains at a constant temperature it must radiate as much heat as it absorbs. The average temperature of the earth, over a period of years, can be considered as being fairly constant and, therefore, the surface of the earth must radiate as much heat as it absorbs. This radiation takes the form of waves of a much longer wave length than that of light and is much more readily absorbed by the water vapor of the atmosphere. This results in practically all of the heat radiated by the earth being absorbed by the layer of the atmosphere next to the surface and then being reradiated in a step-by-step fashion to the succeeding layers above and finally to space.

The air close to the surface, having a high water vapor content, absorbs nearly all of this long wave energy from the earth. Becoming warmer it expands, decreases in weight and is, therefore, caused to rise by the buoyant force of the cold, dense air from higher altitudes which sinks and takes its place. As this warm air rises it loses heat in two ways — by radiation to surrounding air and through the fact that the decreasing pressure permits further expansion which is a cooling process. The latter factor results in the fairly regular rate of decrease in temperature which is found in the lower altitudes (up to 11 kilometers).

It is a well known physical fact that the amount of heat which any body will radiate decreases very rapidly as its temperature falls (the rate at which heat is radiated is proportional to the fourth power of the absolute temperature of the body). The rate of absorption of heat, however, does not vary with the temperature. Considering these two facts observe the situation existing in the atmosphere. In the lower levels the temperature of the air is sufficiently high that the rate of radiation exceeds the rate of absorption and cooling takes place. As the rising air is cooled, due to radiation and expansion, the rate of radiation decreases until finally a temperature is reached where the energy radiated is just equal to that absorbed. When such a condition exists a constant temperature results and the convection currents will rise no more.

A very good summary of the situation existing in the earth's atmosphere is drawn up by Humphreys in the following statement: "We therefore have two distinct atmospheres that intermingle but slightly: a lower or inner one with a large negative temperature gradient, and an upper or outer one with a small positive gradient; floating on the first like oil on water. The lower contains two thirds to three fourths of the entire mass of such gases of the air as oxygen, nitrogen, and all members, except helium, of the argon family; a still greater proportion of the carbon dioxide and nearly all the water vapor." A diagram showing the relative positions of the regions of the atmosphere is shown in Fig. 1.

The stratosphere is of particular interest at the present time due to the possibility of using it as a lane for long distance air travel. It is the peculiar characteristics of this region; its freedom from storms, moisture and high winds and the rarified atmosphere composing it, which make it

desirable for this purpose. The greatest handicaps to air travel at present are the storms, fogs, and winds encountered in the lower atmosphere. The elimination of these hazards will mean a long step in the direction of safe flying.

The main factor in limiting the speed of aircraft is the resistance offered by the air. If the density of the air is reduced to one ninth or less of the sea-level density, as is the case in the lower level of the stratosphere, a much higher speed could be attained — in fact must be maintained to provide the necessary supporting force. There are obviously many difficulties involved in the design of such aircraft due to the intense cold and diminished supply of oxygen existing at this altitude. These problems are not beyond solution, however, and it is entirely probable that the near future will see this hitherto untenanted region of our sphere succumbing to the advance of science.

The Kennelly-Heaviside Layer

We will next turn our attention to a region which exists far above the one which we have just been considering. Beginning at a height of some fifty miles above the earth's surface and extending probably as far as any traces of atmosphere are found (300 - 500 miles up) is a region in which there exists a state of strong ionization. To this region has been given the name of the Kennelly-Heaviside layer in honor of the two men who first made use of its existence in theories regarding the propagation of radio waves.

Under ordinary conditions most gases are relatively poor conductors of electricity, but when subjected to certain types of radiation such as X-rays, cosmic rays, ultra-violet light, and radiation from hot bodies and flames it is found that the gases become, to a varying extent, conductors. This is due to the fact that when subjected to such influences the neutral atoms of the gas are broken down into particles known as ions which have electric charges associated with them. The nucleus of the atom carries a positive charge and is quite massive in comparison to the negative ions or electrons of which more than one may be included in an atom. Under normal conditions the electrons combine with the nucleus and the charges are neutralized. It is only when the positive and negative ions are dissociated from one another that their charges become noticeable.

This process is known as ionization and the charged ions obey the laws of attraction and repulsion between charged bodies. Therefore, when such an ionized gas exists between two points of different electrical potential the electrons will be attracted to the point of positive potential and the positive ions will flow toward the negative point, and this movement of the charged particles constitutes an electric current. The extent of such ionization is dependent upon the strength of the ionizing influence, the nature of the gas, and its density. If the number of neutral atoms is too great the electrons will rapidly recombine with positive ions and the amount of ionization will be smaller than in a gas of less density where the possibility of recombination is not as great. When the ionizing influence is removed or weakened this same recombination into atoms having no electric charge occurs.

A situation of this nature exists in the atmosphere which is a mixture of gases. The most important ionizing medium is the ultra-violet radiation of the sun. Because the portions of that radiation which are most effective as ionizing agents are absorbed in the outer layers of the atmosphere and because of the recombination by collision permitted in the dense lower atmosphere we find that the ionization increases with altitude. From sea-level up to a height 30 or 40 miles above the earth's surface it is almost negligible and the air is considered to be non-conducting. With further increases in altitude ionization increases very rapidly and in the rarified outer portions it is probably complete. It is this region of strongly ionized atmosphere which is termed the Kennelly-Heaviside layer.

The position of the sun obviously has a very marked effect upon this layer. In the daytime the region of strong ionization descends much closer to the surface than

at night, when the absence of the ultra-violet radiation causes recombination of the ions in the lower levels. Even with the ionizing agent removed, however, there are certain regions in the outermost portions of the atmosphere where ionization persists all night, because the gases are so rarified that there is little likelihood of the electrons colliding with the positive ions. Thus the Kennelly-Heaviside layer is said to rise at night and descend during the daytime. The seasonal variation in the position of the sun has the same effect and the average height of the layer is lower in summer than in winter.

We are interested in the Kennelly-Heaviside layer from a practical standpoint due to its effect upon radio communication. All experimental evidence indicates that such communication is carried on by means of electromagnetic radiations of a nature similar to light. When the scientists of the nineteenth century attempted to utilize the theories of light in explaining the propagation of radio waves difficulties were encountered. For instance; light waves normally travel in straight lines and if radio waves did likewise it was impossible to explain how radio transmission from a point on one side of the earth could be heard at a point on the other side without traveling through the earth, which was known to be a powerful absorber of such radiations.

In order to eliminate this difficulty both Heaviside and Kennelly in 1902 brought forth the idea of an ionized conducting layer in the upper atmosphere which reflected or refracted the radio waves back to earth. This theory was further developed by Eccles, Larmor, Appleton and others but convincing evidence of the existence of such a layer remained lacking until about 1922 when wave lengths below 60 meters came into general use in radio transmission. In this new waveband a very new ands trange phenomenon evidenced itself and could be explained only by resorting to the Kennelly-Heaviside layer theory.

This phenomenon is concerned with the way in which the received signal strength decreases as the distance from the transmitter is increased. When the sending

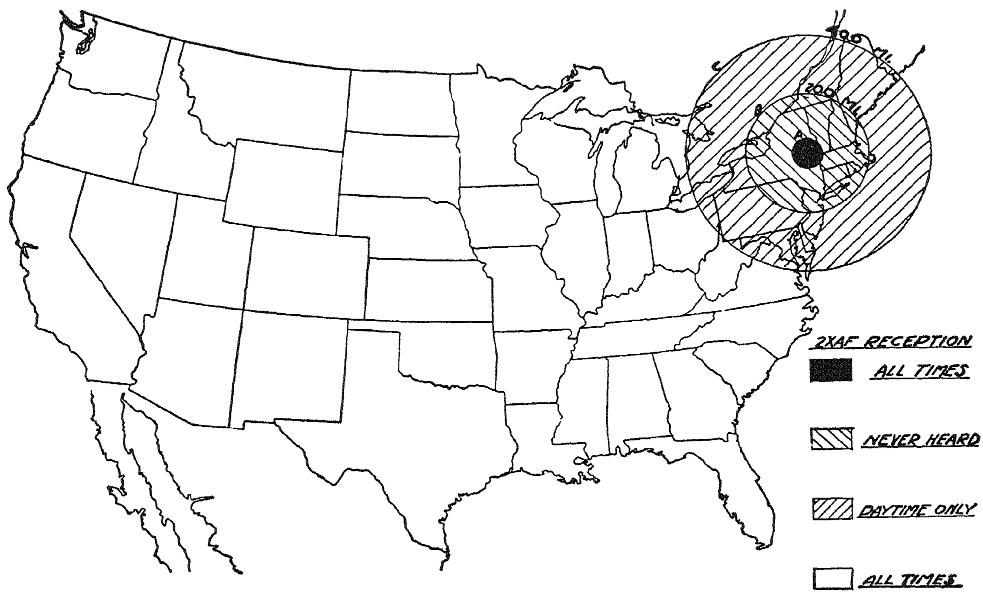


FIG. 2. A TYPICAL EXAMPLE OF SHORT-WAVE RECEPTION.

station is using wave lengths above 60 meters, which were the only ones in use prior to about 1922, it is found that the strength of the received signal is gradually but continually reduced as the distance between the transmitter and the receiver is increased. An entirely different situation exists, however, when the propagated wave is less than about 60 meters in length. In this case as the distance from the sending station is increased the received signal is weakened much more rapidly for a given power transmitted than if longer waves are used. It then dies out altogether and the signal cannot be heard for quite a distance. As the distance from the transmitter is further increased, however, a point is reached where the signal suddenly reappears with great strength. As the receiver is moved from this point still further outward the signal gradually decreases in strength with sometimes other "dead spots" and "reappearances" until it is finally heard no more.

The radial distance between the point where the signal first "dies out" and the point where it is again heard is known as the "skip distance". It is found that this "skip distance" does not appear when wave lengths above approximately 60 meters are used and that it increases as the wave length is decreased below that value. Observations show also that this distance for a given wave length varies greatly with the time of day and with the season — being much greater at night than in the daytime and greater in winter than in summer.

A typical example of this phenomenon may render it more clearly understood. Consider the diagram shown by Fig. 2. Station 2XAF at Schenectady, N. Y. broadcasts on a wave length of 35 meters. Up to a distance of approximately 50 miles (circle A) from 2XAF its signals can be heard at all times. All receivers located between the circles A and B, however, are never able to obtain satisfactory reception from this station. In the area lying between circle B and C Schenectady can be heard in the daytime but not at night. All receiving stations located outside of circle C, that is over 400 miles from Schenectady, can hear it very strongly at all times. In other words, while the signals from 2XAF may be very strong in Chicago it is impossible to hear them in Syracuse, N. Y. The distance between circles A and B is the daylight "skip distance" and that between circles A and C is the night "skip distance". It should be understood that the values used in this illustration are only approximate — actually they vary widely with location, time, and season.

It is this strange action which is encountered in dealing with short radio waves which has brought the Kennelly-Heaviside layer theories to the fore in the past ten years, for it is only by their use that a reasonable explanation of the "skip distance" phenomena can be had. There are several variations of the generally accepted theory of radio wave propagation but nearly all have a common ground in that they make use of the theories of optics as applied to light. One of the most widely accepted hypotheses will be briefly discussed.

Radio waves are considered to be electromagnetic waves propagated in all directions from the sending station. This emission is generally classified into two groups of waves — those which follow along the earth's surface and those which are sent upward at various angles. The former are called the "ground waves" and it has been found that the shorter the wave length the more readily is the energy of these waves absorbed by the earth and surface objects. The "sky waves", as the latter group are called, enter the region of the atmosphere which is ionized and, due to the change in electron density, they experience a very appreciable increase in velocity which causes them to be refracted or bent — for the same reason that light waves are bent when passing from water into air. If the wave has not been propagated at an angle too near the vertical and if its energy is not too greatly absorbed this bending will be sufficient to cause the wave to be returned to the earth's surface. It is found that the degree of ionization necessary to cause

sufficient bending of the wave to bring it back to earth varies inversely with the wave length — that is, the long waves penetrate the ionized region only slightly before being returned whereas the short waves must travel a greater distance in the layer before being sufficiently refracted. It is also believed that the energy of the long waves is much more readily lost in the ionized region than is that of the very short waves. Both of these factors will be referred to in the following discussion.

The diagrams shown by Figs. 3 and 4 illustrate typical examples of the propagation of long and short waves respectively. Only a representative few of the countless ray paths are traced. Where the transmitted wave length is long the ground wave is absorbed much less than in the case of short waves and the sky wave penetrates the Kennelly-Heaviside layer only slightly before it is reversed in direction. The sky wave, therefore, returns to earth before the ground wave becomes inaudible which accounts for the fact that there is no "skip distance" above 60 meters. The waves which leave the transmitting antenna close to the vertical are never bent sufficiently to return to the surface and they are either absorbed or lost to space.

For transmission at approximately 60 meters and below, the ground wave is rapidly absorbed and the sky wave must penetrate into the ionized region so far before being bent back that it returns to earth at a point beyond which the ground wave was too greatly weakened to operate a receiver. There appears, therefore, at 60 meters wave length, or thereabouts depending upon the height of the Kennelly-Heaviside layer, a distinct gap between the point at which the ground wave disappears and the first sky wave returns to the surface. This gap is the "skip distance" and it rapidly increases as the wave length decreases and as the height of the ionized region is raised, for both of these influences result in the radio wave reaching a greater height before being refracted back to earth. From the diagram it is seen that the waves which leave the antenna at an angle just high enough to

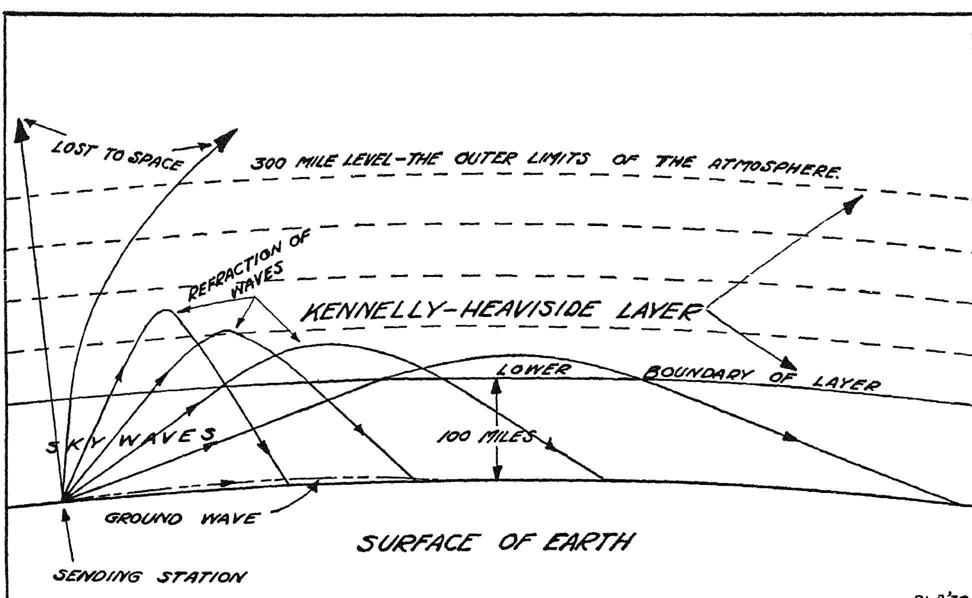


FIG. 3. PROPAGATION OF LONG WAVES

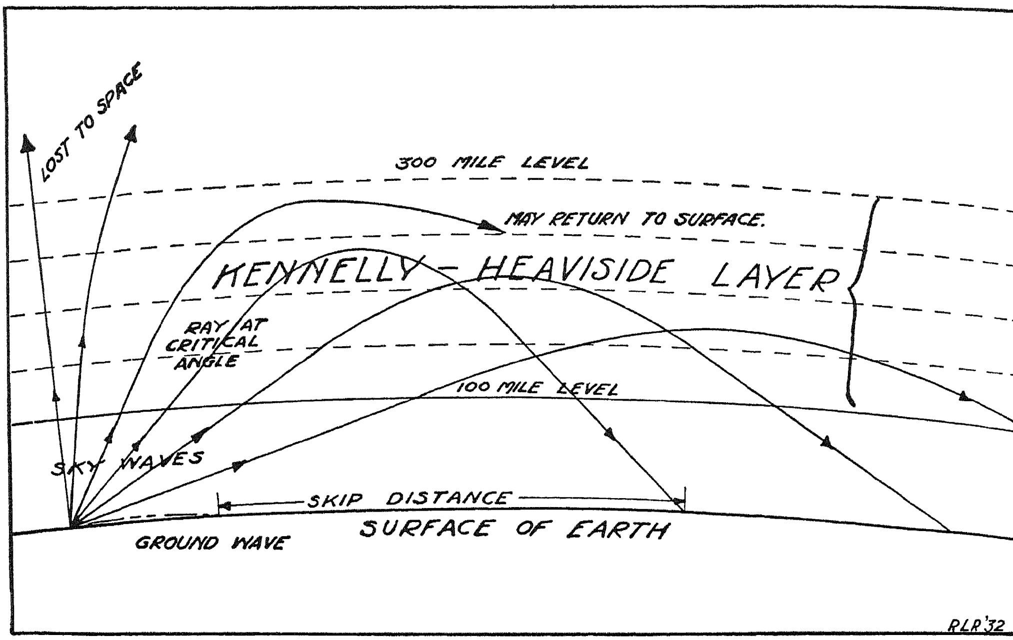


FIG. 4 PROPAGATION OF SHORT WAVES.

escape the absorbing effect of the ground are the ones which return to earth at the greatest distance. This fact is made use of in long distance transmission by building antenna systems which radiate most strongly at such low angles. As the angle of propagation is increased the point at which the ray returns to the surface comes closer to the sending station until a critical angle is reached which gives the shortest distance. Waves which leave the antenna at an angle closer to the vertical than this critical angle either return to earth at some distant point, as shown on Fig. 4, or else they escape from the earth entirely and are lost in space.

Any theory advanced to account for the existence of, or the phenomena evidenced by regions such as the stratosphere or the Kennelly-Heaviside layer must be largely a synthetic one — that is, built up to satisfy certain observed facts. The future progress of science will either prove, disprove, or modify such hypotheses, but until such time they are valuable in that they furnish a foundation upon which a better understanding of actualities may be built and from which further research may be projected. Very often a correct knowledge of the fundamental action or results of some device or phenomenon has been obtained despite the use of a theory which was either partially or entirely wrong. So in this case, no matter if the theories just advanced are the object of ridicule in future years, they serve their present purpose in that they give us a better understanding of the practical problems at hand and a foothold for future development. Knowledge regarding both the stratosphere and the Kennelly-Heaviside layer is far from being complete and these two regions, together with many allied subjects, furnish fields for very important experimental and theoretical research.

One of the most successful flights since Piccard's pioneering journey into the stratosphere was that undertaken by Captains Albert W. Stevens and Orvil A. Anderson, of the U. S. Army. On November 11, 1935, in the nine-ton balloon, *Explorer II*, they rose some 72,000 feet. This and other such flights have already contributed much to our knowledge of the intensity and direction of cosmic rays and the position and composition of the atmospheric layers.

THE WHITE DWARF STARS

by

SAMUEL L. BOOTHROYD, C.E.

Professor of Astronomy and Geodesy, Cornell University

FROM time immemorial the star Sirius has been admired and even worshipped and praises of its beauty expressed in song and legend. Being the brightest star in the sky it was especially noticed and observed by early man, as it slowly moved through the Milky Way. Hence the legends of its plunging through the milky stream of heaven. Modern man has found the star to be even more wonderful and thought-provoking than early man, even with his vivid imagination, could conceive it to be. In fact it is almost trite in this connection to quote from Herbert Dingle's *Modern Astrophysics* where he observes: "We are beginning to understand that what man can imagine, Nature can achieve. But what is not so generally recognized is that there is one science in which the facts not merely equal anticipations, not merely transcend them, but are so astounding that, until they were discovered, they had no counterpart in imagination at all."

The first modern discovery about Sirius which laid the foundation for the new discoveries about this amazing star, was made by Edmund Halley. It is a much more important discovery than the comet which has made his name famous.

In the Philosophical Transactions for the year 1718 Halley published a paper which revealed the fact that since the observations of Timocharis and Aristyllus about 300 B. C. and Hipparchus about 130 B. C. the stars Aldebaran, Arcturus and Sirius had moved more than half a degree in a southerly direction on the sky. Before this the only facts which were contrary to the dogma that the stars were fixed and unchangeable was the occasional appearance of a new star which suddenly blazed out where no star had before been seen. The most famous of the new stars or Novæ, at the time of Halley, were: — The Star of Hipparchus in 134 B. C.; A star in Aquila in 389 A. D.; Tycho's star in Cassiopeia in 1572 A. D.; P Cygni, a third magnitude nova observed by Jansen in 1600 A. D ; Kepler's star in Ophiuchus in 1604 A D. and 11 Vulpeculae a third magnitude nova observed by Anthelm in 1670 A. D. As these novæ were seen to suddenly blaze out where no star had previously been seen, slowly increase in brightness for a few days and then gradually fade to invisibility in a few weeks, they were soon forgotten by practically everyone but the few who saw them and the dogma that the stars are fixed and unchangeable was hardly shaken by these spectacular exceptions. However, when Halley announced that three of the brightest stars in the sky have, in two milleniums, moved over half a degree, the dogma of the fixity of the stars was forever shattered. This apparent movement of the stars on the sky background is referred to as their proper motion and after Halley's discovery of the proper motion of Sirius, Aldebaran and Arcturus, it was discovered that many stars were slowly changing their positions on the sky. By August 10, 1844, Bessel was able to announce that the movements of Procyon and Sirius on the sky were not

uniform and in the case of Sirius contained a periodic element as he had first suspected ten years earlier. He suggested as an explanation that these stars, which appeared as a single orb, were really double, one component being bright and visible and the other faint and invisible. The two components Bessel conceived to be in orbital motion about their common center of mass, which itself was in uniform motion. Thus the motion of the visible component would have a periodic element as the center of the system moved uniformly across the sky, just as a light on the rim of a wheel would have a periodic motion as the wheel turns while its center moves uniformly forward. By an almost uncanny prescience Bessel associated this periodic element in the proper motion of Sirius with Tycho's novæ.

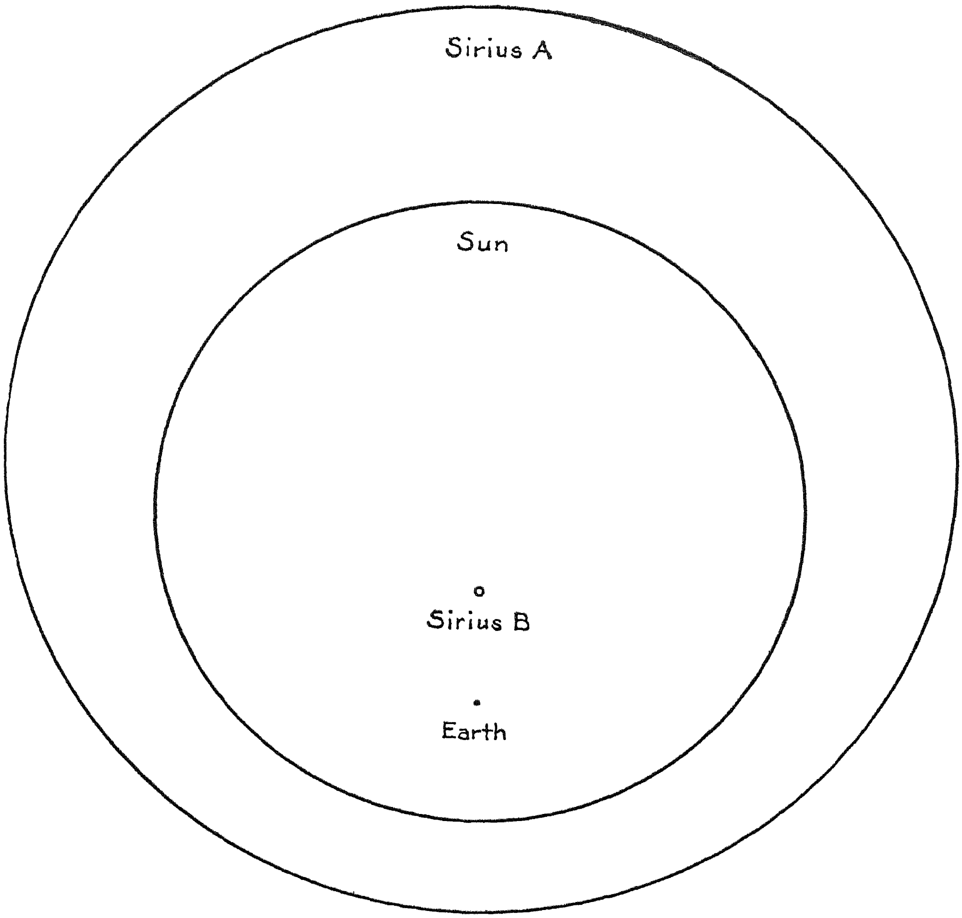
On the basis of Bessel's work and later observations Safford, in September 1861, assigned the direction from Sirius A, in which his companion, Sirius B, should be seen. On January 31, 1862, Alvan Clark, when testing the lens of the Dearborn 18-inch refractor which he was just completing, directed the telescope to Sirius and saw the companion in the position predicted by Safford.

For all purposes, except the determination of the relative masses of the two components of a binary star system, we may consider the relative orbit in which the smaller star moves around the larger one, instead of considering the absolute orbit of each component about the center of mass of the two. There are only four stars nearer than the Sirian system and consequently, being one of the nearest stars and being a binary, the mass of the system is known very accurately and the shape, size and position of the orbit is known with a high degree of accuracy, as is also the period of revolution. The latter comes out almost exactly the fifty years predicted by Bessel from the sinuous motion of the bright component. Also from the ratio of the amplitude of the sinuous curve traced by Sirius A to the angular distance between the two components, the relation between their masses may be derived.

The mass of Sirius A is found to be 2.44 times the mass of the Sun and the mass of Sirius B is 0.95 times that of the Sun. All of the facts so far enumerated were known with fair accuracy at the end of the last century. It was also known that Sirius B was only about one ten thousandth as bright as Sirius A and that Sirius A emits about thirty times as much light as the Sun. It was further realized that if we knew the surface brightness of each star, we could find the areas of their surfaces and hence their diameters and volumes and therefore the density of each star. Very rough estimates of the surface brightness of Sirius B showed that it must be very small compared with Sirius A and hence very dense.

The spectroscope gives the means of analyzing the light of a star and determining, with the aid of proper heat measuring instruments, the energy distribution in the spectrum. Where this is known, the surface brightness can be determined. Applying these principles to Sirius A, we find that each square inch of area of the star must emit 15.03 times as much energy as does each square inch of the Sun's surface. Since the total energy emitted is 35.60 times as much as the Sun emits, the area of Sirius A is $35.60 \div 15.03 = 2.38$ times that of the Sun. This makes the diameter of Sirius A about 1.5 times the diameter of the Sun and its volume nearly 3.5 times that of the Sun. Hence its density is about 0.8 that of the Sun, or a little more than the density of water. This is about what we should expect for a normal, well-behaved dwarf star.

To find the corresponding quantities for Sirius B is not such an easy matter, because, first, it is very faint, and a very large telescope is required to get sufficient light from so faint a star to obtain its spectrum. Secondly, Sirius B is so near to the bright Sirius A that it becomes very difficult to get its light without having a large admixture of that of Sirius A. The great 101-inch reflector at Mount Wilson finally made it possible to get the spectrum of Sirius B sufficiently free from light of Sirius A to give a good value of the surface brightness of the former.



RELATIVE SIZES OF SIRIUS A, SUN, SIRIUS B AND EARTH.

The results of the measurements show that each square inch of the surface of Sirius B emits 3.79 times as much energy as does each square inch of the surface of the Sun. Since the total output of energy is only one three hundred and sixty-third the total output of energy of the Sun, the area of the surface is (1/363) /3.79 = one thirteen hundred and eightieth of that of the Sun.

The diameter of the star is then found to be one thirty-seventh of the Sun's or about three times that of the Earth. This makes its volume 27 times that of the Earth.

Imagine then a small but very brilliantly white body, a little smaller than the planet Uranus, revolving around a glorious orb which has a diameter 165 times the diameter of the Earth. The smaller body swings around the larger one in an elliptical path in a period of 50 years. In 1893 they were only 762 million miles apart, while in 1918 they were 5115 million miles apart and in 1943 they will again be 762 million miles apart.

But the most amazing fact remains to be told and, though we know it to be a fact, we cannot imagine it. When we realize that the small, bright body is al-

most as massive as the Sun or, to be exact, has only 27 times the volume of the Earth, but contains 316,000 times as much material, we are amazed. When reduced to comprehendable figures and we find that an average cubic inch of the star would weigh 2200 pounds at the surface of the Earth, our credulity is at first stretched to the breaking point and we inquire if there is not some flaw in our reasoning or in our measures. When, however, we approach the question by an entirely independent method and find the same result, we are forced to accept the evidence and realize that here is one of those facts which Dingle refers to, which had no counterpart in the imagination at all.

Besides Sirius B, there are certainly known three other white dwarfs of exceedingly high mean density, and two other known stars almost certainly white dwarfs. One of the three first mentioned is the companion to Procyon which was suspected by Bessel since the little Dog Star also showed irregularities in its proper motion. The mass and volume of Procyon B are not so accurately known as for Sirius B but the data is sufficiently accurate to make certain that Procyon B is even denser than Sirius B, being of an order of density such that an average cubic inch of Procyon B would weigh 15 tons at the surface of the Earth. The density of the other two known white dwarfs is of the same order as that of Procyon B.

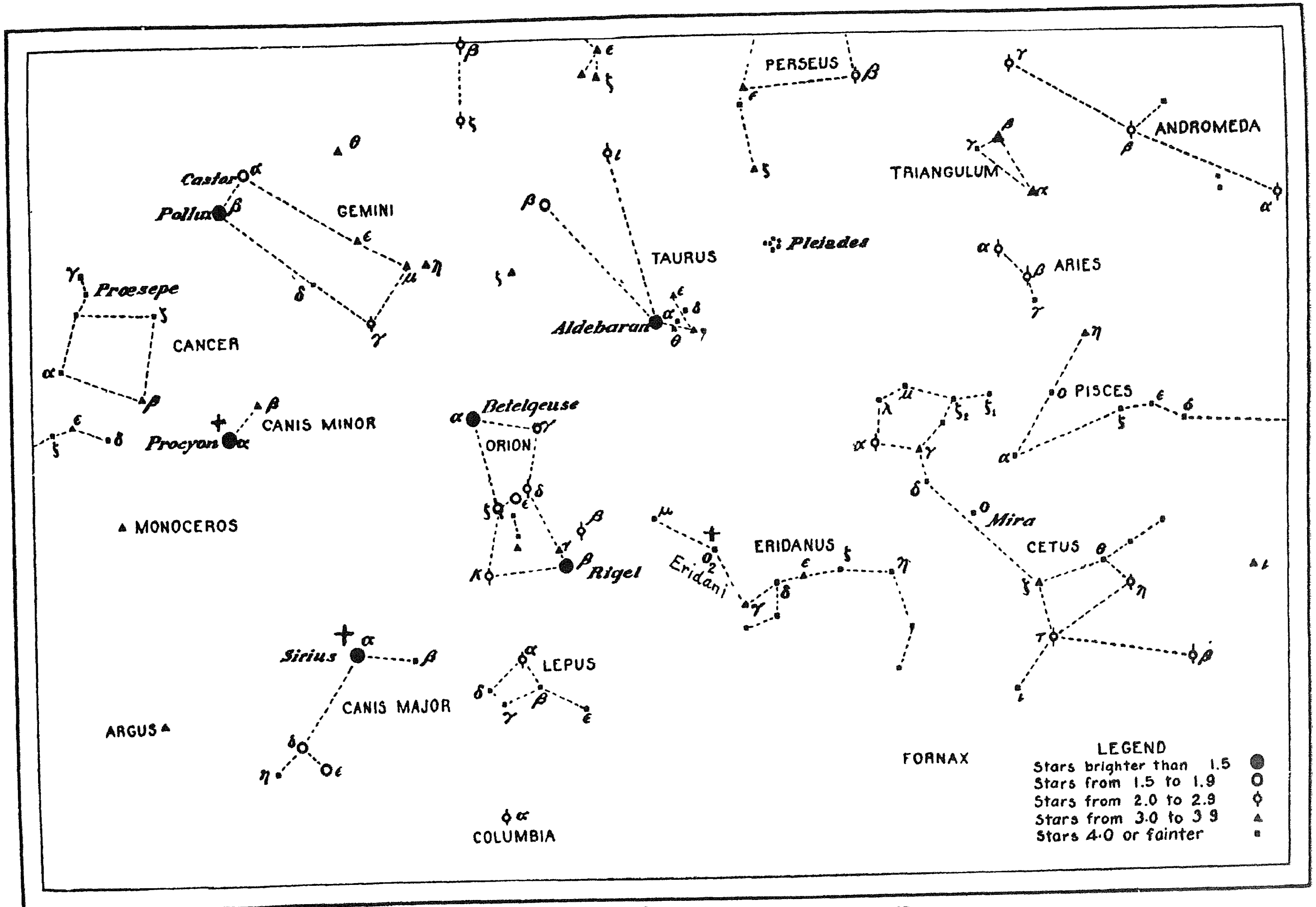
Of the four known white dwarf stars, three are one companion of a binary system, i.e. Sirius, Procyon and Omicron Eridani. The fourth is a single star and is known as Van Maanen's star. All of these known white dwarfs are within sixteen and a half light-years distance from the Sun. Within a sphere of such a radius, there are about thirty known stars. Because of their diminutive size, the white dwarfs are the faintest known stars, so it would not be strange if there are several more within that distance from the Sun. In this connection it is interesting to observe that about one star in nine is binary. If this holds for all binaries, then there should be 27 white dwarfs which are single to every three that are members of binary systems. Unless, then, our immediate region of space has more binary systems in which one member is a white dwarf than is true in general, there should be 27 white dwarfs which are not members of a binary system within sixteen and a half light-years distance from the Sun. Perhaps among the thousands of millions of faint stars, some at least may be white dwarfs quite near to us. Sirius B, Procyon B and the faint companion of Omicron Eridani might easily have escaped attention, as Van Maanen's star did until less than two decades ago, if they had not been members of a binary system in which one member is a star of high luminosity.

If even six more white dwarf stars exist within sixteen and a half light years of the Sun, there are then thirty-six stars in a sphere whose radius is sixteen and a half light years and ten of these are white dwarfs. This is not an unreasonable assumption and, if true, there is about one white dwarf to three which are just ordinary dwarfs, such as our Sun, Sirius A and Procyon A. At any rate, whether ten out of thirty-six stars are white dwarfs or whether four out of thirty are, we see that white dwarf stars are not very rare.

One of the most interesting classes of stars are those whose light varies, known generally as variable stars. Among these novæ are perhaps the most spectacular and Cepheid variables are often regarded as the most interesting. Certainly the latter have served us most usefully, through the period-luminosity relationship, in enabling us to sound the depths of space.

Henry Norris Russell once remarked that if we knew the cause of the variation in the light of variable stars, we could understand the evolution of the universe.

Experimental, observational and theoretical researches by many physicists, astronomers and astrophysicists are revealing the hidden mysteries of the atom and of stars, showing us how matter can assume such diverse forms as we find in nebulæ and comets' tails, where it is so



PART OF GIRDLE OF STARS 45° NORTH AND SOUTH OF EQUATOR

Sirius, Procyon and O_2 Eridani marked by +, Van Maanen's Star not visible to the naked eye

rare that our best vacuum is dense matter in comparison, to white dwarf stars and atomic nuclei, where a cubic inch would weigh from one ton to forty million tons at the surface of the Earth.

If we knew just how a star converts its material into radiant energy, we should probably be able to write the whole life history of every star.

Recent researches by Eddington, Jeans and Milne indicate that the matter in stars is wholly gaseous even for the very dense white dwarfs which have been revealed by the studies of Sirius and Procyon referred to earlier in this chapter.

The very dense, highly-ionized gas in the interior of white dwarf stars has been given the name "degenerate gas".

Milne, in a recent paper, presents the theory that the change from the state of gas in a normal star, such as the Sun, to the degenerate state found in a white dwarf, takes place suddenly — that the star literally collapses from a normal state to a white dwarf. When the event occurs, a vast amount of energy is suddenly released and we witness a Nova, or new star, as it is called. If the star had a rotational speed faster than a certain critical speed when it collapsed, it would divide into two, and one or both parts might re-expand and become a normal star. If only one part expanded, we should have such a system as Sirius or Procyon, in which one star is a normal star and the other a white dwarf.

Milne's theory is only in its infancy but it gives promise of accounting for Novæ and Cepheid variables, including the period-luminosity relation for Cepheid variables, as well as for all variable stars and many, if not all, binary stars.

As Milne truly says: "We now see the truth of Bessel's prophetic remarks, originated by his pursuit of researches initiated by Halley. Halley discovered the proper motions of the stars by a study of Sirius. Bessel discovered the irregularity of the proper motion of Sirius and predicted the existence of an invisible companion, subsequently found. Adams determined its spectrum and Eddington computed its density and accounted for its high value by the theory of ionization and the kinetic theory of gases. Einstein's Theory of Relativity, with Adam's measures of the shift of the spectral lines of Sirius B, confirmed the values found by Eddington. R. H. Fowler identified the dense state with that of a degenerate gas in the light of researches by Fermi and Dirac. Fowler's researches opened the way for an intensive study of the configurations of masses consisting of a degenerate gas at a high density surrounded by a gaseous envelope of more familiar type. The properties of their configurations not only give insight into the structure of the white dwarf stars, but suggest possibilities as to the structure of the stars generally. These properties afford possible explanations of the Nova phenomena, the Cepheid phenomena, the mass-luminosity correlation, the relationships of the massive, highly-luminous stars to one another and, lastly, the general relationship of the dense stars, like the white dwarfs and the nuclei of planetary nebulæ to the other stars of nature."

To repeat Bessel's word concerning the first known white dwarf: "These phenomena seem to possess interest in relation to our knowledge of the physical con stitution of the universe."

THE WONDER-WORKING X RAYS

The Story of Radiations That Have Opened New Paths of Knowledge

by

HELEN MERRICK

IN recent years the walls that once rigidly separated physics and chemistry have been crumbling away. It now seems prophetic of this trend that one of the first steps toward the discovery of X rays was taken by a scientist who was both a chemist and a physicist, Sir William Crookes, an Englishman (1832–1919).

Crookes was interested in the effects of electrical discharges through gases at low pressure. To help him in his experiments he invented a device which became known as the Crookes tube. It was a tube from which the air had been pumped; this created a vacuum, or rather a partial vacuum, since some air had to remain in the tube if it were to work. Metal wires were sealed into opposite ends of the tube. These wires served as electrodes to which a source of electric current could be attached; the current could then be sent through the air that still remained in the device.

One day, as Crookes was sending a high-voltage current through his tube, he noticed that photographic plates in a closed box near by became fogged while the current was flowing. At the same time he also observed a mysterious green glow in the tube. Crookes, however, was concerned only with protecting his plates. He cured the fogging simply by removing the plates to another room whenever the current was flowing. For some reason the strange phenomena do not seem to have aroused his curiosity.

Our story skips a few years, to the autumn of 1895. Wilhelm Konrad Roentgen (1845–1923), the German physicist, was puttering with a Crookes tube in his laboratory at the University of Würzburg. Turning on a high-voltage current, he noticed the effects that had already attracted the attention of Crookes: the green glow; the fogging of photographic plates. Roentgen was not satisfied to let it go at that. He tried covering the tube with black paper, through which no visible light could pass, and still something came through that affected a photographic plate. He came to the conclusion that this something must be invisible rays, and he called them "X rays" because "X" stands for the unknown in science. (X rays are also called roentgen rays for their discoverer.)

The story goes that Roentgen, by a lucky accident, also discovered one of the properties of X rays. While he was experimenting with the Crookes tube, some photographic plates in a desk drawer had been blurred. Instead of throwing the spoiled plates away, he developed them. On one plate he was amazed to see the perfect image of a key appear; yet no key had been in the drawer. Then he remembered that a key had been on the top of the desk. The key had been photographed right through the desk by the X rays. Roentgen also found that the rays would pass through his hand when he inserted it between the tube and a plate. In the developed photograph, however, the bones stood out clearly as dark shadows as compared with the flesh. This indicated that the bones, more dense than the flesh, must block the rays to some extent, and therefore that the rays pass more easily through less dense materials.

The green glow that Crookes and Roentgen saw was light-waves being sent out by the glass walls of the tube when electrons bounced against them, as the result of the discharge of electricity through the small amount of gas in the tube. (Electrons are

atomic particles that carry a negative charge of electricity; and ordinary electric current is really a flow of electrons.) At the same time, the electrons were stimulating the atoms of the glass to send out waves of extremely short length, the X rays. Since then, physicists have learned that X rays are produced when electrons strike any atoms at high speed and, conversely, that when X rays strike atoms, electrons are hurled out.

It was finally proved that X rays are similar to those of ordinary light, though they differ in wave-length. This is how it was proved:

Since the time of Sir Isaac Newton (1642–1727) it had been known that visible white light consists of a number of different colors; and that white light may be broken into bands of these colors, since each color has a different wave-length. Red, at one end of the spectrum, has the longest wave-length; violet, at the other end, the shortest. When white light passes through a prism, each color is bent according to its wave-length, red the least and violet the most, and we get the rainbow array of the visible spectrum.

Early X-ray picture of a hand. In the faint shadow of flesh, the bones stand out clearly. The rings appear black, as they blocked the rays completely.

A more exact way to break up white light is by use of a device called a diffraction grating. Diffraction is the term for the property of light-waves to bend outward and spread out as they meet an opaque substance in their path, or go through a slit or hole in it. One kind of diffraction grating consists of a system of lines drawn very close together on a glass plate. The lines are parallel and the same distance apart, and there are usually thousands of them to the inch. Light is blocked by the lines, but passes through the extremely thin slits between them. Each color is bent according to its wave-length (more exactly than by a prism); the spectrum falls on a screen behind the grating.

Von Laue proves that X rays are similar to visible light-waves

Now a German physicist, Max von Laue, was familiar with the diffraction grating. In 1912, he had the brilliant idea that a crystal, such as diamond or rock salt, might separate X rays into beams of different wave-lengths. This, of course, would prove that they do behave like light-waves. A crystal came to mind because by this time physicists suspected (and later proved) that a crystal is a conglomeration of atoms arranged in a perfectly regular plan at very short distances from each other. It seemed to Von Laue that such an arrangement might act as a natural diffraction grating, with openings between the atoms small enough to diffract X rays if they really do have shorter wave-lengths than those of visible light.

Von Laue's reasoning was sound. When a narrow beam of X rays was sent through a crystal, dark spots appeared on a photographic plate behind the crystal. It was found that the position of these spots depended on the different wave-lengths in the X-ray beam and also on the arrangements of the atoms in the crystal.

Sir William H. Bragg, a British physicist, and his son, Sir William L. Bragg, carried Von Laue's work still further, and soon obtained clear, sharp spectrum lines

with X rays. The Braggs developed what is called the law of crystal diffraction. Using this law, if a scientist knows the wave-length of the X rays he can find out how the atoms are spaced in the crystal; or the process can be reversed—if the scientist begins with knowledge of how the atoms are arranged, he can then work out the wave-length of the X rays.

To describe all the experiments, theories and calculations that were involved in this work would fill volumes. Summing up, it not only furnished the key to the nature of X rays but also to the structure of crystals. Most non-living, solid matter is crystalline in structure.

We know now that X rays are a part of the electromagnetic spectrum: that is, they are related to radio waves, heat or infrared waves, visible light-waves, ultraviolet and gamma rays, and rays that accompany cosmic radiation. X rays belong in wave-length between ultraviolet and gamma rays (gamma rays are given off by radium and other radioactive elements). All electromagnetic waves travel through space at the same speed, about 186,000 miles per second.

The angstrom unit for wave-lengths

Wave-lengths of the electromagnetic spectrum are expressed in terms of the angstrom unit, named for the Swedish physicist Anders Jonas Ångström (1814–74). One angstrom is 1/100,000,000 (.000,000,01) of a centimeter, or 1/253,-999,800 of an inch. A scientist expresses it as $1\ \text{Å} = 10^{-8}$ cm. The symbol λ stands for wave-length expressed in terms of angstroms. Thus λ 5,890 means "wave-length of 5,890 Å."

Visible light has wave-lengths ranging from 4,000 to 8,000 Å. X rays range from about 250 Å (overlapping the ultraviolet) down to about 0.06 Å (overlapping the gamma rays).

An important point to remember here is that the shorter the wave-length, the greater the energy of the ray; and the greater the energy, the more penetrating the ray will be. For this reason X rays and the tubes that produce them are classified as "hard" or "soft." Hard rays have the shorter wave-lengths and thus are more penetrating.

A descendant of the simple Crookes tube with which our story began, the modern X-

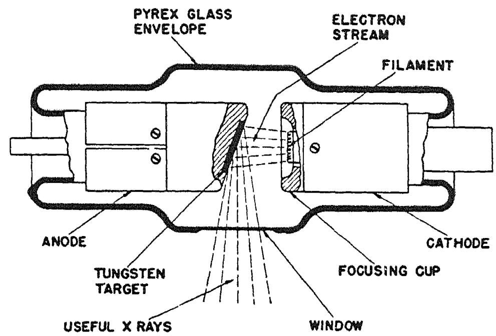


Diagram of a modern X-ray tube Useful rays, streaming through the tungsten (wolfram) target shown in the drawing, pass out through a window.

ray tube works on the same principles. It consists of a bulb containing as nearly perfect a vacuum as possible, fitted with electrodes to which high voltage can be applied. The negative electrode is called the cathode. It is usually a filament of wolfram (tungsten) wire wound into a spiral. The positive electrode (the anode) is called the target. It is made of some heavy metal such as wolfram because it must be able to withstand tremendous heat without melting. Ordinarily the target is attached to a molybdenum rod and supported by an iron sleeve which helps to radiate the heat.

When an electric current of high voltage is turned on, the cathode is heated white-hot and sends out a stream of electrons, or cathode rays, which are pulled through the vacuum by the high voltage until they reach speeds of thousands of miles per second. They slam against the atoms of the target, and as they strike, a spurt of X rays splashes out.

To explain where the X rays come from, we must go inside the atom. Whirling around the atom's nucleus, or core, are one or more electrons—in the case of a heavy metal there are many—each in a definite shell, or path. If an electron is forced to jump out of its shell, some kind of ray is emitted. Visible light is sent out when an electron is displaced from an outer shell.

If the disturbance is much more violent, an electron in an inner shell, close to the nucleus, is likely to be dislodged and removed from the atom entirely. The atom cannot remain in this unbalanced state. So an electron from the next outer shell jumps into the vacant place. The second shell is soon filled by an outer electron jumping in, and so on. Balance is restored when the atom picks up a free electron (there are always some free electrons drifting around in a metal) for its outermost shell. X rays are the result of disturbance in the inner shells.

How higher voltages affect X rays

As we have indicated, it requires more energy to displace the electrons close to the nucleus than it does to displace any others in the atom. The higher the voltage in an X-ray tube, the faster the cathode rays will be pulled through it, increasing their energy. As a result the wave-lengths of the X rays given off from the target will be shorter, approaching the wave-lengths of gamma rays, and the X rays will be more penetrating. In giant X-ray tubes, built to stand millions of volts, the cathode rays may reach almost the speed of light (about 186,000 miles per second) and X rays are produced that will easily go through several feet of concrete.

As we have seen, one of the first properties of X rays to be noticed was their ability to penetrate solid substances such as wood, flesh and metal. However, X rays cannot be focused, or brought to a point, easily as visible light-waves can. One reason for this is that an X-ray beam of the same wave-length does not penetrate all substances equally well. We mentioned earlier that the depth of penetration depends partly on the density of the substance. Ordinary X rays, produced at 100,000 volts, pass through flesh easily but through bones less so. Nevertheless, X rays cannot pass through glass easily, as light does; and the softest X rays are absorbed even by air. One of the most effective materials to block X rays altogether is lead. For this reason, glass containing lead is used on many kinds of X-ray equipment to protect those who work with it and are endangered by X rays.

Another important property of X rays is that, like light, they act on the chemicals of photographic plates, fluorescent screens and so on. This X-ray action together with the penetrating property makes it possible to take "shadow" pictures of, say, the inside of the human body or of a metal casting. Bombarded with X rays, some chemicals fluoresce: that is, they glow brightly as long as X rays strike them. One of the best-known uses to which this property has been put is in the fluoroscopic screen, which we shall explain when we take up the medical uses of X rays in more detail.

When a gas, such as the air, is exposed to X rays, it becomes ionized: that is, some of its atoms or molecules acquire an electric charge. (We explain ionization elsewhere in THE BOOK OF POPULAR SCIENCE.) The amount of ionization produced serves to measure the strength of the X rays.

Still another property of X rays is that when they fall on a substance, other rays are given off, which also consist largely of X rays. This "secondary radiation" is partly like that of the original X rays but is also dependent on the kind of substance exposed. Thus the scientist has another tool with which to study the structure of matter.

Effect of X rays on living tissue

X rays also have an effect on living things. When X rays are absorbed, they change the structure of tissues, and these will be "burned" or destroyed if the exposure is long enough. Some kinds of X rays are also able to effect the genes, the elements in the germ cells of reproductive organs by which hereditary traits are passed on from one generation to the next. In this way heredity itself may be changed.

Considering the ability of X rays to probe matter and force it to yield its secrets, however grudgingly, it is hardly to be wondered at that X rays play a primadonna role on the stage of scientific research. Practical application of new findings frequently follows so swiftly in many fields that it is difficult to separate the pure research from the everyday use.

Perhaps no field has been more rewarding to the scientist than the kind of analysis called X-ray crystallography, which began with the work of Von Laue and was developed further by the Braggs. The methods used in this field are too complicated to discuss within the brief limits of this article. To put it as simply as possible, when a narrow beam of X rays is sent through a crystal, the rays are scattered by the atoms and form a balanced pattern, which can be caught on a photographic plate. Each kind of crystalline solid has its own pattern. One result of this work is that scientists now have an accurate knowledge of the character of X rays sent out by each of the chemical elements, knowledge that has helped to determine the internal structure of the atoms themselves. In fact, in what is called X-ray spectroscopy, the rays reveal information about the patterns of the electrons inside the atom.

From this kind of research, it has been a fairly easy step to investigate the arrangement of molecules in various chemical substances. They may be "fingerprinted" by the way in which X rays are scattered in passing through.

A comparatively recent development is the branch of science called X-ray absorptometry. Scientists can measure the quantity of certain materials in a chemical compound by a device that shows the amount of X rays absorbed. The device is so sensitive that it can register the difference between ninety-nine and a hundred sheets of thin paper. One practical use is to measure the amount of "ethyl" in gasoline. X-ray absorptometry is possible because atoms can absorb X rays. An atom of oxygen, say, absorbs the same amount of rays whether it is in the form of the element or in a compound with other elements; and under the simplest conditions, the amount of absorption is the same whether the substance containing the oxygen be a solid, a liquid or a gas. So the amount of energy taken from a beam of X rays passing through a given mass of a substance is always the same, whether the substance is hot or cold, or a gas, a liquid or a solid.

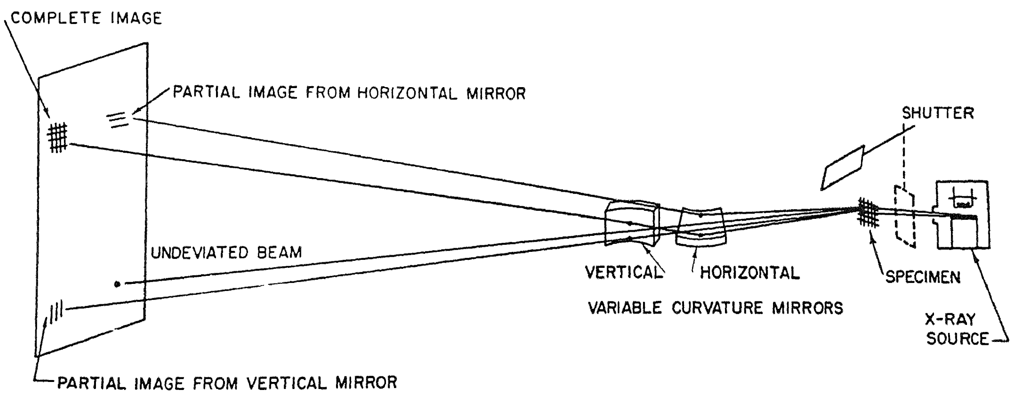


Diagram of the way the X-ray microscope works. The specimen is placed in front of a shutter between the X-ray source and two concave mirrors with their faces at right angles to each other. Partial images are produced when rays are reflected from one mirror. The complete image results when rays bend up from the horizontal mirror and then bend out from the vertical mirror. X rays can be bent only at a low angle and only from the surface of a substance (reflection) and not in passing through (refraction). The diagram has been simplified in order to explain the workings of the microscope.

Even art has benefited. X rays can be used to analyze the composition of pigments in oil paintings—to the point where sometimes the painter of what appears to be an "old master" can be identified.

The first X-ray microscope was introduced in 1950. It uses a combination of X rays and visible light-waves; and because of the penetrating power of X rays, it reveals finer detail than is possible with optical microscopes.

In order to increase the penetration of X

rays, scientists have been building ever more powerful machines. A giant among them all is the betatron—really an outsized X-ray tube. This machine was first invented in 1941 by Donald William Kerst, of the University of Illinois. He called it the "betatron," from beta ray, which is a stream of high-speed electrons.

As you may guess, a betatron is an enormously complicated apparatus. Essentially it consists of a doughnut-shaped glass tube, containing a vacuum, that is placed between the poles of a powerful electromagnet. What is called an electron gun is arranged so that it will send a stream of electrons into the tube at a certain angle. Inside the tube, two forces act on the electrons: one makes them follow the curve of the tube, and the other gives them higher and higher speeds, increasing their energy enormously.

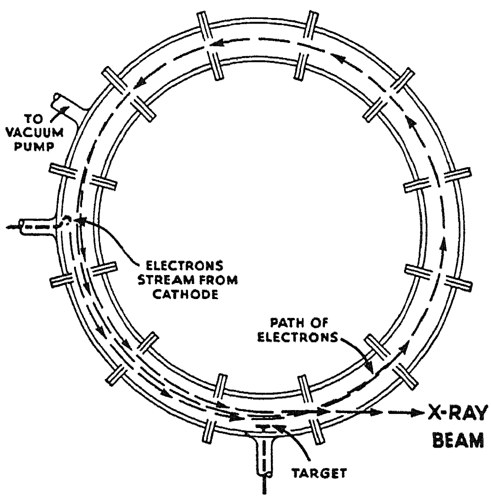


Diagram of a betatron Arrows in the tube show the path of the electrons. At the instant their path is bent and they strike the target, X rays spurt out.

At a chosen instant, they are bent from their curved path and directed to the X-ray target. All this happens in the twinkling of an eye; nevertheless during this time the electrons circle the tube many thousands of times. These operations are repeated over and over again.

In our daily lives, most of us are first introduced to X rays in the office of a dentist or a doctor. From what has been said, you can now understand why X-ray photography is so helpful in dentistry and medicine. Abscesses at the roots of teeth, an open safety pin in a baby's throat, a bullet in a splintered bone—all can be detected with X rays.

You may also have had your chest, say, examined with a fluoroscope, which makes use of the property of X rays to cause certain chemicals to glow. One advantage, for some purposes, of the fluoroscope over X-ray photography is that the fluoroscope allows a doctor to observe the inside of the body in action.

A fluoroscopic screen consists of a piece of cardboard (which X rays can pass through easily) coated with certain crystals, such as platinobarium cyanide or tungstate of calcium, which fluoresce under X rays. In an examination, the patient stands or lies down between an X-ray machine and a fluoroscopic screen, which the doctor can place against any part of the body. In some cases, such as an examination of the stomach, the patient usually drinks a liquid first, often a compound of barium, which blocks X rays. (Naturally, the liquid is harmless to the patient.) When the current is turned on in the X-ray machine, bones and thick organs, or organs such as the stomach that are full of the barium compound, cast shadows on the screen because they are blocking the X rays, and the rest of the screen glows. For the best results, of course, the fluoroscope should be used in a blacked-out room.

X-ray photography itself has been improved by the development of a method for taking pictures in three dimensions. Heretofore, the pictures were "flat," showing only width and length. The new method adds depth, so that the doctor may see the inside of the body in actual perspective. Another method, invented by a Swedish scientist, Dr. Arne Frantzell, permits pictures of veins and other soft tissues such as muscles, fat and the skin around bones to be taken in great detail.

X rays also have a place in the treatment of disease, particularly of tumors, the most evil of which is cancer. A tumor is a new growth of cells that serves no purpose in the body and grows at its expense. If the

With the fluoroscope, X rays explore the inside of the body in action Special gloves and apron protect the physician from overexposure to rays

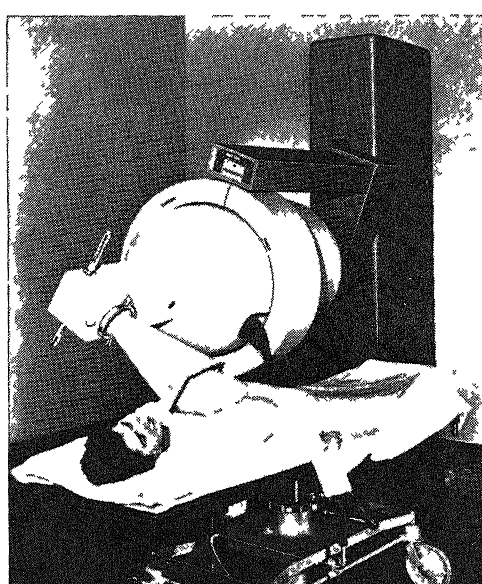
growth stays in one place, it is called a benign tumor—one that does not usually endanger health or life. But if the new cells show a tendency to spread to other parts of the body, the tumor is said to be malignant, or cancerous. A tremendous amount of research is being done to discover the cause and cure of cancer, but so far it remains beyond the help of any known drug. At this stage only surgery, radium (by the action of the extremely short gamma rays that it sends out) or X rays offer hope to the victim of cancer.

The action of X rays on living cells is mainly a destructive one. However, young cells and actively growing ones succumb to X-ray action more quickly. Also lymph tissue is more susceptible and some kinds of cancer spread by way of the lymph vessels. Cancerous cells are usually young and grow much more rapidly than healthy ones, so it is possible to adjust the strength of the X rays and limit the exposure with the result that only the cancerous cells are attacked and healthy cells are affected very little, or not at all.

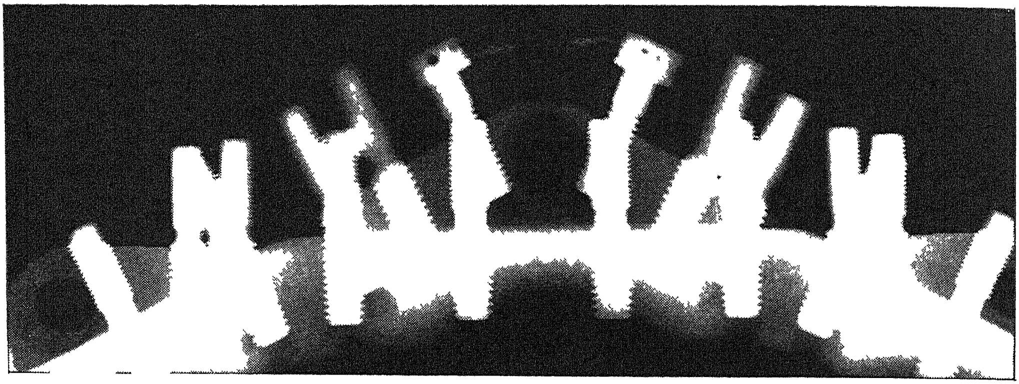
Great care is necessary. The roentgenologist (a medical X-ray specialist) must be able to control the dosage precisely. X-ray machines for medical treatments are complicated affairs, with a number of precision measuring devices. Tumors on or near the surface of the body may be treated with X rays produced at 100,000 to 200,000 volts, but tumors that lie deeper may require rays from tubes of higher voltage, running into the millions. "Millions of volts" may sound alarming, but there is no danger of shock. The machines are completely insulated, and the dangerous part of the equipment is kept outside of the treatment room One of the largest X-ray machines for treatment—2,000,000 volts—thus far built is in use at the Hospital for Joint Diseases, in New York.

A few cases of malignant tumor, considered hopeless, have even been treated with a 23,000,000-volt betatron. There were no harmful effects from the treatment on the patients, and the tumors that could be examined had shrunk.

Improvements in X-ray-treatment techniques are coming fast. An X-ray shield, developed by Dr. Hirsch Marks, of the New York City Cancer Institute, is one example. It permits extremely high-voltage



A 250,000-volt X-ray machine for treatment. The rays come out of the square funnel, and a bag keeps them concentrated on the area being treated.



A "shadow" picture for aviation engineers. It shows part of an airplane crankcase. From this photograph the engineer can tell the exact position of the studs (white objects) and how deep they penetrate.

X rays to be trained on a tumor without damage to healthy cells. Radiation dosage is measured in terms of a unit called the roentgen, "r" for short. Without the shield, the highest safe dosage is about 200 r in air per treatment, up to a total of 3,300 r over a period of four weeks. With the shield, Dr. Marks reported, 1,200 r in air a day may be given for twenty days of treatment—in all, 24,000 r.

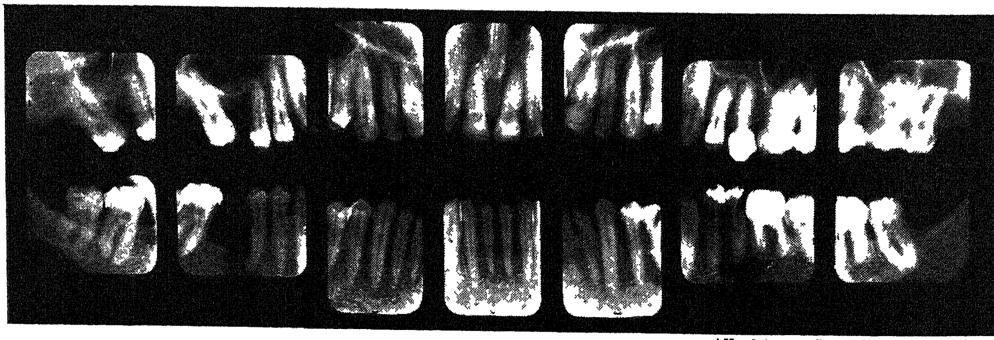
The industrial applications of X rays are legion, and we have space to mention only a few here. X rays are used to examine metal coatings, plastics, rubber insulation and so on, whose flaws might not appear on the surface. High-pressure boilers and pipes, for instance, are X-rayed to be sure that there are no weak places that might cause explosions. Some machines are large enough to take an X ray of an entire automobile. Most X-ray machines, however, concentrate on smaller areas.

Shadow pictures can show whether an egg is good or bad, and whether the core of a golf ball is perfectly round.

Airplane propellers are X-rayed periodically, because they show changes in their internal structure some time before they are ready to break.

Up-to-date textile mills also use X-ray equipment. Examination of fibers often shows that a better arrangement of the molecules in a fiber will make it sturdier and so will make stronger cloth.

It was only toward the turn of the century, as we have seen, that Roentgen found the answer to the mysterious green glow in the Crookes tubes and to the fogging in photographic plates. Yet already X rays have probed deeply into the closely guarded secrets of matter and have provided tools that benefit man in thousands of ways. It is likely that further advances are being made even as you read these pages.



All pictures, General Electric Company

A series of X rays of a set of teeth, revealing the parts usually hidden beneath the gums. Such pictures give the dentist precise information with which to guide his work. Solid white patches are fillings.

LIFE WITHOUT GERMS

The Answer to a Great Scientist's Question

ALMOST all living creatures, including man, are continually surrounded by a host of microorganisms (tiny living things)—bacteria, molds, yeasts, viruses and protozoa (one-celled animals). These tiny plants and animals, also known as germs, or microbes, inhabit the air we breathe, the food we eat, the water we drink and the earth upon which we live. They invade and powerfully affect the blood system, the breathing apparatus and the intestinal tract of animals.

The great French bacteriologist Louis Pasteur raised the question whether the higher forms of life could exist at all without microorganisms, particularly those that are found in the intestinal canal. Many biologists pondered over this question. It occurred to some of them that something more than mere theory was involved. Suppose that researchers succeeded in raising animals in a germ-free environment, so that they would be free of germs during the whole of their lives. These animals would offer the most interesting possibilities.

For one thing they would supply bacteriologists with a supremely useful tool. The bodies of animals normally contain many different kinds of germs. A bacteriologist utilizing such animals can never be certain that the conditions revealed by his microscope are due to the specific germ that he is studying. But if he could experiment with a germ-free animal, he could accurately determine the effects of a given germ, since no other microorganism would be involved.

The early efforts of biologists to raise germ-free animals were not very successful. By 1913, however, such animals could be kept alive for short periods of time. Later, the life span of the animals was increased and their growth rates were measured. The first successful results on a truly significant scale were produced in the bacteriological laboratories of Notre Dame University. The experiments of James A. Reyniers, director of the laboratories, and his associates opened up a new era in the investigation of germ-free animals.

Reyniers first became interested in the problem while doing research on the nature of the bacterial cell. He found that his bacteria cultures were constantly being contaminated by unwanted microbes, and he tried to find a way to exclude these uninvited organisms. He succeeded in protecting his cultures from contamination by means of containers that could be sterilized and then sealed. To test their effectiveness, Reyniers tried to raise germ-free animals in them. After much experimentation he succeeded; the glass containers he used were sterilized with germicide and supplied with air filtered through glass wool. In the years that followed, Reyniers' equipment and techniques were steadily improved. In the apparatus that is used today, microbe-free animals breathe sterile air and eat sterile food; they mature, breed and die in a germ-free environment. Sterilization is brought about by heat, chemicals and ultraviolet radiation.

The basic germ-free cage is a steel cylinder five feet long and three feet in diameter. Welded to one side of the cylinder is a smaller cylinder called a sterile lock, through which food and other materials are passed from the outside into the sterile cage. Food, instruments and other materials are sterilized in this lock before being transferred into the cage proper. Waste products, cultures and the animals themselves are removed from the

main cylinder through the sterile lock

The cage has a Pyrex observation window, through which experimenters can view the interior. Technicians, stationed outside the cage, handle and feed the animals with arm-length rubber gloves extending into the cage through ports; the gloves are sealed to the edges of the ports. The cage and its contents and the surfaces of the rubber gloves are sterilized by steam under pressure before animals are brought into the cage.

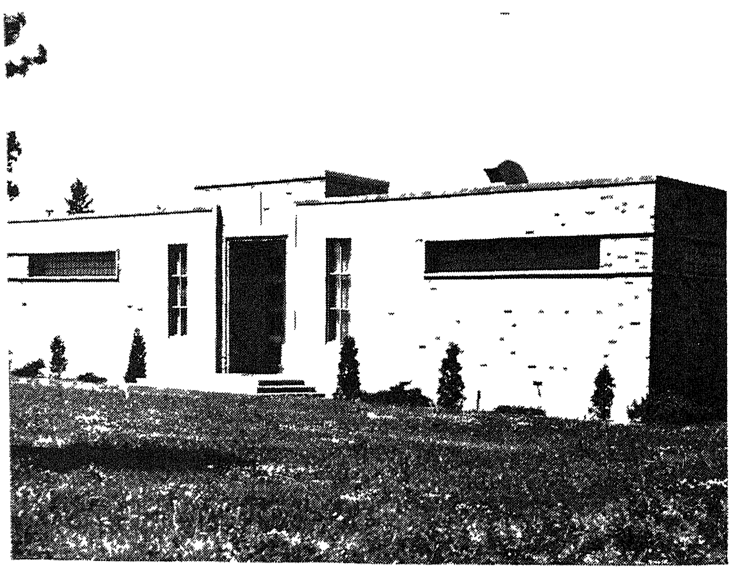
Many different kinds of cages are constructed on this basic design. There are raising cages where animals are housed. There are operating cages in which instruments and animals can be conveniently handled. A special transfer cage makes it possible to transfer animals from one kind of cage to another — for example, from the operating cage to the raising cage.

Hundreds of animals can be housed in a large tank built on the same principles of design and construction as the basic cage. The germ-free animals dwelling in such a tank are attended by a staff member, clad in a plastic diving suit; he takes a shower in a germicidal spray and a dip in a germicidal bath before entering the sterile animal quarters. All units are ventilated by air that passes through copper pipes containing a certain amount of glass wool.

The animals used in germ-free-life experiments include guinea pigs, chickens, monkeys, cats, dogs, rats, mice, insects and even fish. These animals must be germ-free to begin with. In the case of mammals, for example, the young are delivered from the germ-free womb of a pregnant female by Caesarean operation performed in a sterile operating cage after the mother has been anesthetized and scrubbed well with a germicidal solution. In the case of chicks the matter is simpler. Fertile eggs whose shells are sterilized by the germicide mercuric chloride are placed in a sterile cage where they hatch.

The feeding of new-born animals presents many problems. Young mammals must be fed hourly with a specially prepared formula; later they must be weaned to a solid or semi-solid diet. They are fed by hand by means of a small capillary tube. The tip of the tube is a special latex nipple similar to the mother's nipple. Chicks are fed a sterile chick food. All foods are carefully sterilized by steam under pressure.

Once germ-free animals breed, the labor of caring for the young is considerably reduced, for the jobs of feeding and weaning no longer have to be assigned to



The new Germ-Free Life Building at Notre Dame University This building houses specialized equipment for the raising of germ-free animals.

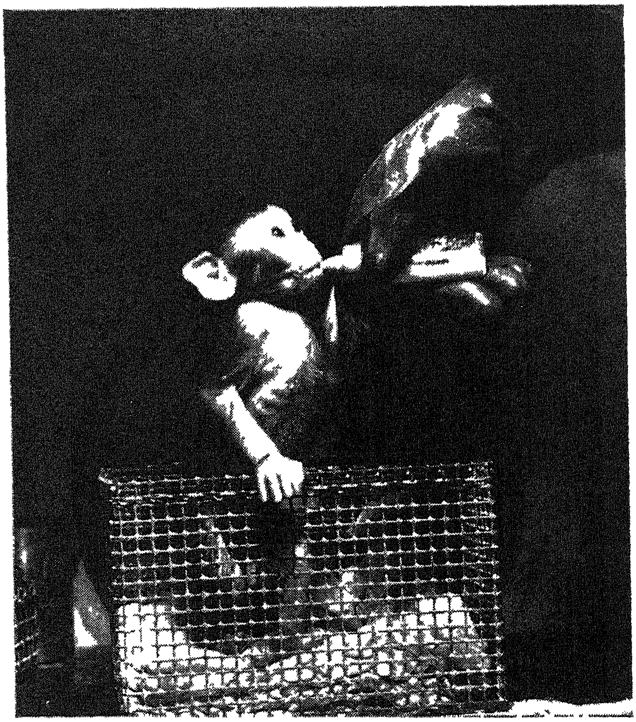
a staff of specially trained technicians.

Each animal is frequently examined to see if it is germ-free. Samples of bodily secretions, hair or feathers, food, milk, water, urine and feces are collected. These samples are sealed in test tubes; they are then removed from the cages by way of the sterile lock and are rigorously tested for any traces of living microbes.

There can be no doubt that the experiments in the germ-free laboratories at Notre Dame have already answered Pasteur's question about the possibility of life free from germs. These experiments have proved that animals can be born, can be

Germ-free insects (such as flies and cockroaches) are raised in simplified apparatus like that shown here. The insects are used in micrurgical studies, involving surgery at the microscopic level.

Standard Reyniers germ-free cages in the main rearing room of the Germ-Free Life Building. Each of these cages has a Pyrex observation window, through which the interior can be viewed.



This baby monkey is being raised in a germ-free cage. An attendant is feeding the animal with an arm-length rubber glove, which extends into the cage through a port.

An attendant, clad in a diver's outfit, is cleaning a cage in a large tank. He enters the tank through a germicidal bath, after taking a shower in a germicidal spray.

raised and can breed in an environment free from microbes. But they have gone far beyond this important point of departure.

For one thing, they have thrown a flood of light on the life processes of animals uncontaminated by germs. We now know that the blood serum of such animals contains few or no antibodies — substances that restrict or destroy the action of bacteria or neutralize their poisons. Germ-free animals have fewer white blood cells and less lymphatic tissue than normal animals. All of these differences are due, in part, at least, to the absence of microbes. When a dead germ-free animal is left in a sterile condition, there is no rotting, or odor or any other sign of decaying flesh.

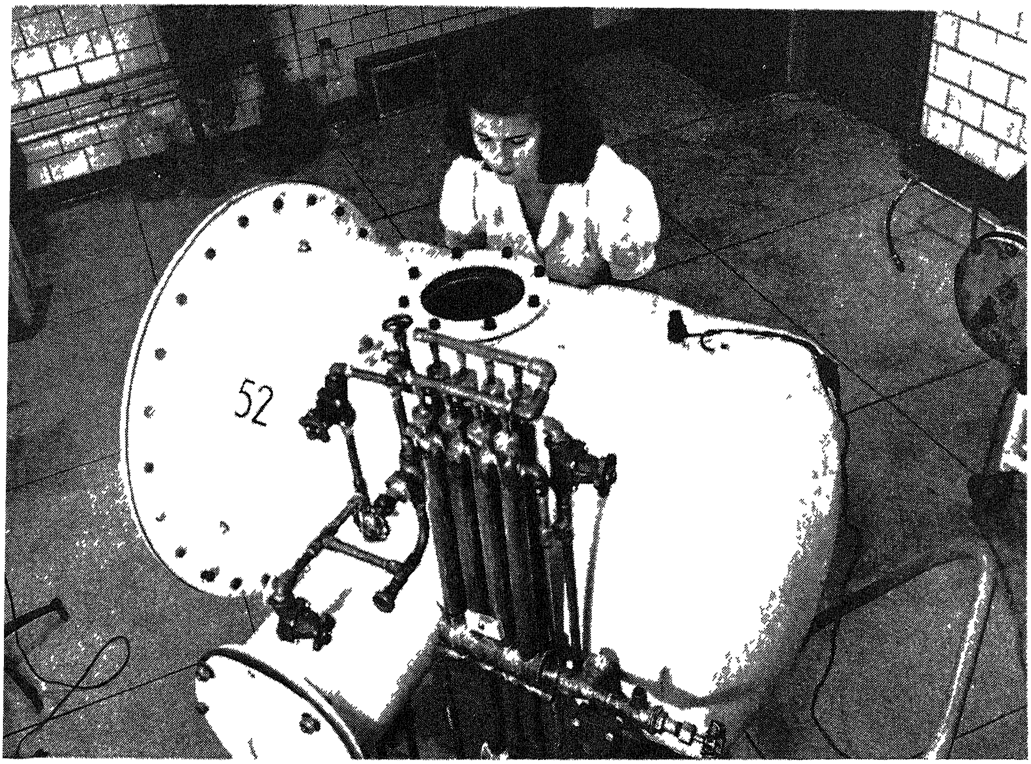
When certain antibiotics, such as penicillin and chloromycetin, are fed to normal poultry, the birds grow considerably larger. There is no such increase in growth when these antibiotics are supplied to germ-free birds. The reason is probably that the latter, in their sterile environment, have already reached their maximum growth.

Germ-free animals have proved ex-

ceedingly helpful in the study of tooth decay. The exact cause of such decay is not known, but some think that bacteria in the mouth are responsible. Since the mouth is contaminated by different kinds of bacteria, it is difficult to single out the actual culprit. The teeth of germ-free animals are free from decay, whatever their diet may be. Therefore, experimenters are able to determine accurately the effects upon the teeth of specific bacteria introduced into the mouth of germ-free animals. They hope in this way to determine which germs are responsible for tooth decay.

Researchers utilizing germ-free animals are making a special study of lymphomatosis, a poultry disease resembling cancer in man. They are investigating radiation sickness. They have turned their attention to the effects of poisoning caused by antiseptics.

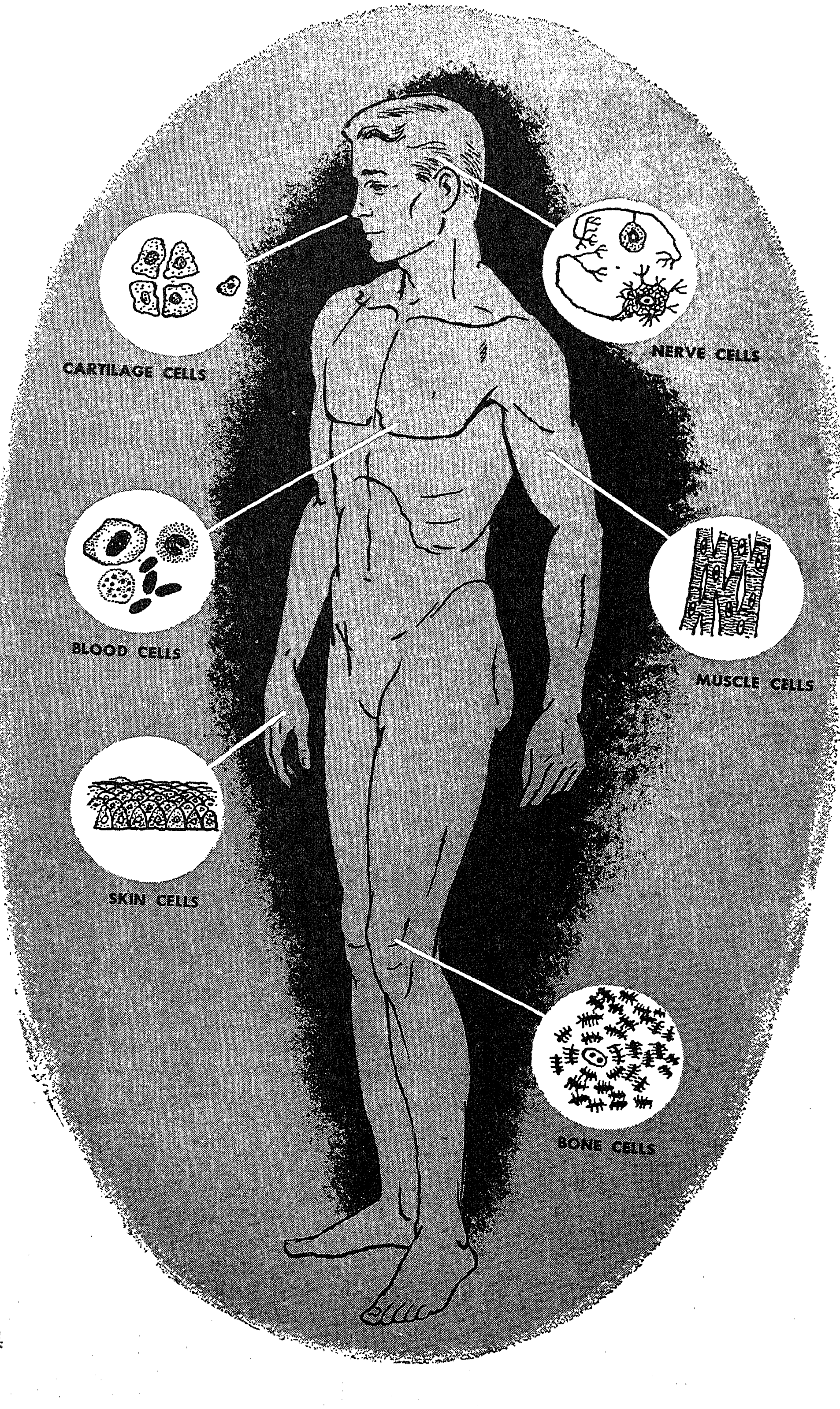
They are also trying to find out whether germ-free animals require the same food constituents as normal ones. Once this matter has been decided, many important dietary studies will be carried out. Researchers will be able to study, more effectively than ever before, the relation of diet to longevity, constipation, reproduction, lactation (milk production), growth and the development of special systems, such as blood and lymph. They will also be able to learn much about dietary diseases, such as pellagra.



All photos, LOBUND Institute

A staff of technicians works around the clock feeding baby animals in germ-free rearing cages. Each cage is thoroughly sterilized by means of steam under pressure before animals are introduced into it.

New research programs are on the way in the LOBUND Institute at Notre Dame. (The name LOBUND is derived from Laboratories of Bacteriology, University of Notre Dame.) New buildings are being erected; more researchers and technicians are being added to the personnel. Director Reyniers and his associates are hopeful that tomorrow's results will overtop today's encouraging progress.


CARTILAGE CELLS
NERVE CELLS
BLOOD CELLS
MUSCLE CELLS
SKIN CELLS
BONE CELLS

Science and Progress (1815-95) VI

by JUSTUS SCHIFFERES

THE CELLS OF ANIMALS AND PLANTS

THE cell is the fundamental unit of living things; or, to put the matter differently, living things must be considered as communities of cells. There are certain one-celled animals, like the amoeba, and one-celled plants, like the diatom. Most animals and plants are made up of combinations of cells. Thus, in a human being we find billions upon billions of cells of different kinds — bone cells, skin cells, nerve cells, blood cells and so on. This is the cell theory of organic structure. Rather dimly foreshadowed in the seventeenth and eighteenth centuries, it was first definitely stated in the 1830's.

The seventeenth-century microscopist Robert Hooke was the first to make out the structure of the cell, or, more exactly, the cell wall. Peering through his primitive microscopes (which he had made himself) at thinly sliced sections of cork, he clearly saw that the cork was divided into numerous compartments. These seemed to fit snugly into one another, like the different sections of a honeycomb. Hooke called these compartments *cellulae,* or cells, because they suggested little rooms (which is what *cellulae* really means in Latin). The cells that he first examined belonged to dead plants; he later observed that there were similar structures in living plants.

A little later, the Italian anatomist Marcello Malpighi, studying sections of plants, observed a number of "little bodies, closely massed together and each surrounded by a wall." The Dutch naturalist Anton Leeuwenhoek and the English plant physiologist Nehemiah Grew also made out cell structures in the tissues of animals and plants. None of these investigators, however, had any idea of the nature and the purpose (if any) of these structures. We discuss these early microscopists in the chapter Science Grows Up (1600–1765) II, in Volume 3.

Probably the first man to point out that cell tissue is found in both animals and plants was the German army surgeon, naturalist and embryologist Kaspar Friedrich Wolff (1733–94). Wolff thought of this cell tissue as consisting of a mass of "cell-shaped" structures. The concept was valid enough, as far as it went, but it was expressed pretty vaguely and it does not seem to have created much stir. Wolff had other quite sound ideas. He pointed out, for example, that living creatures are not machines, as certain mathematicians had implied, since, after all, machines cannot, like living creatures, reproduce their kind. He also indicated various similarities in plant and animal development.

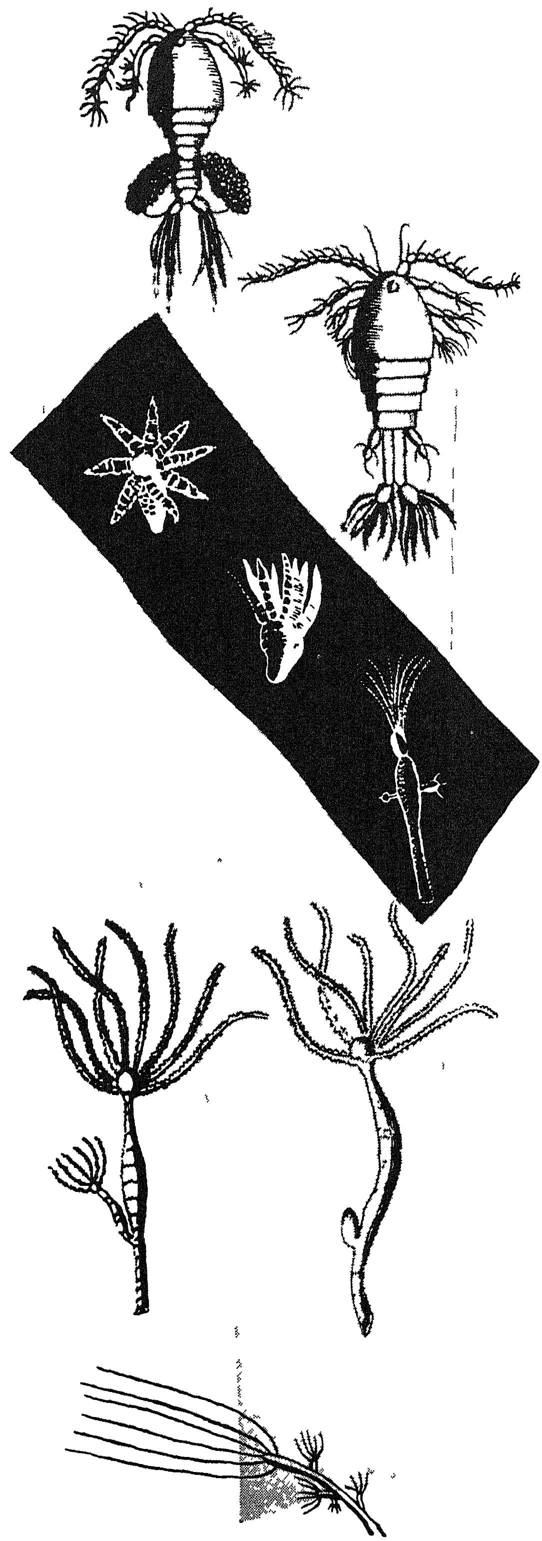
Unfortunately for his reputation, however, Wolff often drew conclusions that were not warranted by the facts at hand. If he could not explain something, he was wont to toss off a clever phrase in order to cover up the gap. It is said that Goethe had Wolff in mind when he had Faust remark to Wagner, his pupil, "If you do not understand a thing, simply give it a long name and then everybody will say what a brilliant fellow you are."

The early microscopists had focused their lenses not only on the minute structure of large organisms but also on the tiny creatures that they called animalcula (little animals). A generation or so later, the animalcula came to be known as infusorians, because they were to be found

in different kinds of infusions. The German natural philosopher Lorenz Oken (1779–1851) pointed out a possible connection between the tiny infusorians and the higher organisms. In his GENERATION, published in 1805, he compared the infusorians to the "vesicles, or cells" found in larger organisms. "All organized beings," he wrote, "originate from and consist of vesicles, or cells. These . . . are the infusorial mass from which all larger organisms are formed or are evolved." This surprisingly acute observation was quite lost, in Oken's book, amid a flood of wild speculation.

The early investigators of cellular structure were greatly handicapped by the imperfect microscopes that they used. The chief defect of these instruments was chromatic aberration — that is, things placed under their lenses shimmered with all the colors of the rainbow, so that microscopists could not be sure of what they saw. Some of them used their imaginations pretty freely in interpreting what their microscopes revealed — or seemed to reveal. For example, some of them imagined they saw a preformed little man — homunculus — in the head of a human sperm cell.

A Swedish physicist, Samuel Klingenstierna (1698–1765), was the first to show how achromatic lenses (lenses free from color distortion) should be made. Acting under his instructions, the English optician John Dollond, in 1758, constructed the first lenses free from chromatic aberration. It was not until the nineteenth century, however, that microscopes were supplied with these improved lenses. In 1827, the Frenchman Chevalier produced the first achromatic lens system for microscopes, thus making it possible to bring very small objects sharply into view. The Italian Amici began the manufacture of achromatic lenses for microscopes at about the same time. In the 1830's, biologists began using the greatly improved microscopes and they made many striking discoveries.

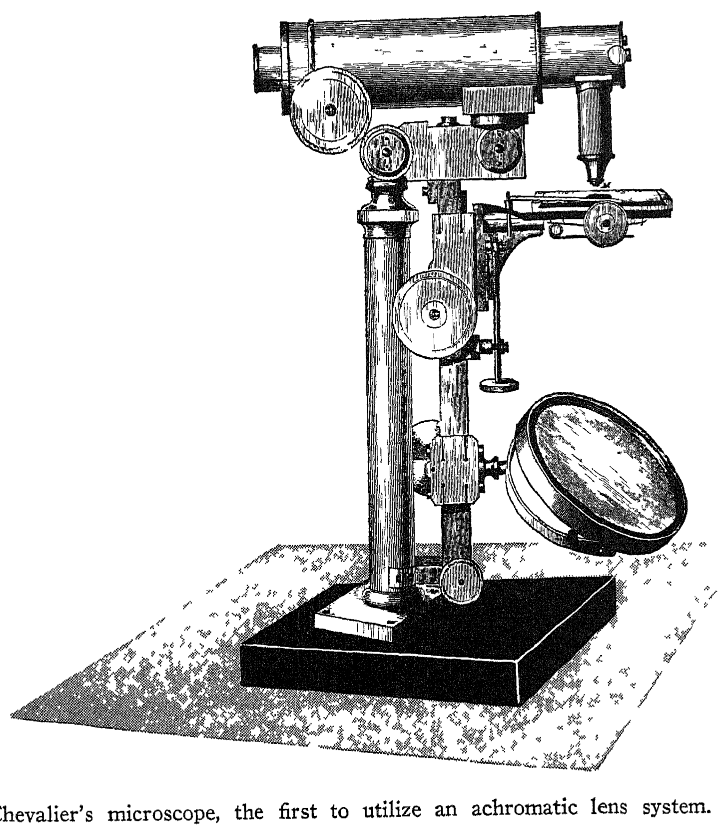


These drawings of animalcules in water are from a treatise by Henry Baker — *Of Microscopes Made Easy,* published in London in 1785.

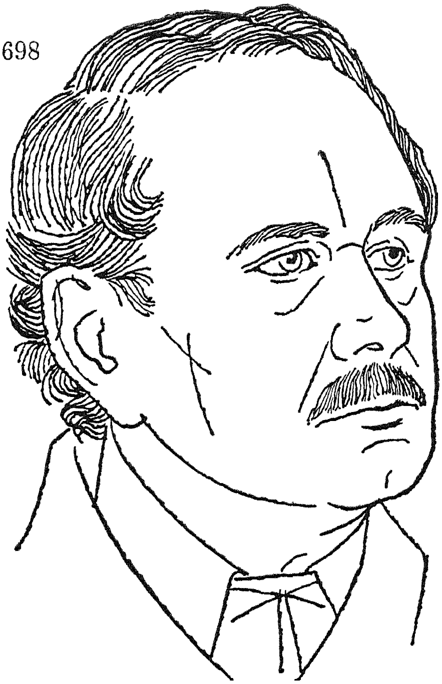
Thus the German botanist Hugo von Mohl (1805–72) convincingly demonstrated that new cells in plants — one-celled algae and higher plants alike — arise through the formation of partition walls in old cells. He showed that a definite cellular structure exists in bast (woody fibers), bark and other parts of plants — a point that had been denied by many previous investigators. The Scottish botanist Robert Brown (1773–1858), the discoverer of Brownian movement (see Index), showed that each cell of the orchid and of various other plants has an internal "key spot," which he called a nucleus, or areole. Johannes Evangelista Purkinje (1787–1869), a Czech naturalist, pointed out that the closely packed cell masses in certain parts of animals resemble cell masses found in plants. A French zoologist, Félix Dujardin (1801–60), observed that the life of one-celled animals is bound up with physical and chemical changes occurring in the jellylike substance of which the cell consists.

These investigations were all forerunners of the modern cell theory of organic structure. The cell theory, as we accept it today, was first comprehensively set forth by Schleiden and Schwann. Matthias Jakob Schleiden (1804–81) was born at Hamburg, the son of a distinguished doctor. He first specialized in the law. But his legal practice, in his native city, was so unsuccessful that in a fit of despondency he shot himself in the forehead. Recovering from the effects of this attempt at suicide, he determined to give up the practice of law and to devote himself to the natural sciences.

He obtained a doctor's degree in both philosophy and medicine, won fame with his scientific writings and became a professor of botany at the University of Jena in 1850. Twelve years later he resigned and, after a brief interlude as professor at



Chevalier's microscope, the first to utilize an achromatic lens system.



MATTHIAS JAKOB SCHLEIDEN

Dorpat (now Tartu), in Estonia, he gave up his scientific work. He spent the rest of his life idly wandering through the towns and the pleasant countryside of Germany.

In 1838, he wrote a paper, On Phytogenesis (origin of plants), for a scientific journal called MUELLER'S ARCHIVE FOR ANATOMY AND PHYSIOLOGY. In this paper he presented the idea of the cell as the essential unit of living organisms. He pointed out that plants that consist of but a single cell — like so many algae and fungi — are nevertheless individual, independent organisms. "Plants developed to any higher degree," he wrote, "are aggregates of . . . independent separate beings — that is, cells themselves . . . Each cell leads a double life; one which is independent and has to do with its own development alone; the other which is incidental, as an integral part of a plant. The vital processes of the individual cells . . . form the fundamental basis . . . for vegetable physiology."

All this is perfectly sound; it is accepted by all biologists. When Schleiden tried to explain the origin of cells, however, he went astray. He advanced the erroneous theory that new cells arise by budding from the surface of the nucleus.

The German naturalist Theodor Schwann (1810–82) worked out the cell theory of organic structure at almost the same time as Schleiden. The son of a Prussian bookseller, he studied at Berlin under a renowned physiologist, Johannes Peter Mueller, and after taking his doctor's degree he became Mueller's assistant. In 1838, Schwann was named professor of anatomy at the University of Louvain, in Belgium. Nine years later, he transferred to the University of Liége, also in Belgium, and here he remained until his death. He refused the professorships that were offered to him at German universities, because he objected to the constant quarreling of German professors.

Theodor Schwann's contribution to the cell theory

Schwann's chief contribution to the cell theory was contained in his treatise MICROSCOPIC STUDIES OF THE SIMILARITY OF STRUCTURE AND DEVELOPMENT IN ANIMALS AND PLANTS, published in 1839. He took as his point of departure certain striking resemblances between animals and plants. In the case of animal cartilages, for example, he pointed out that "the most important phenomena of their structure and development correspond to like processes in plants. These tissues originate from cells, which correspond in every respect to those of plants. During development, too, the cells display phenomena similar to those in plants . . . The cells — the membranes and the cell contents, as well as the nuclei [in animals] — are analogous to the parts with similar names in plants."

Schwann observed that the egg from which, when impregnated by a sperm cell, the animal body originates is really a cell. In mammals the egg (or ovum) is microscopically small in size; in other animals, like the hen, it may be quite large. Yet, large or small, all eggs are cells; in them we can distinguish the nucleus, the cell contents and the cell membrane. The egg produces a young animal by cell division. The single fertilized cell divides into two

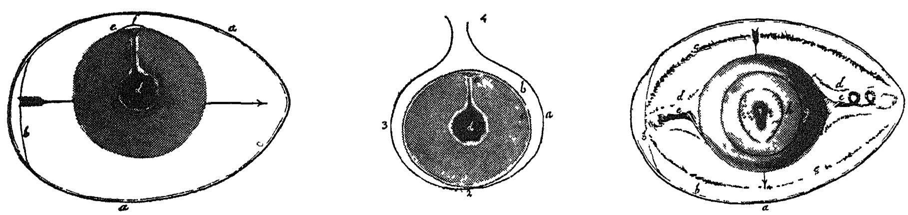
cells, the two into four and so on. The tissues that eventually arise can be distinguished from one another on the basis of the characteristic cells they contain. For example, there are tissues, like the skin, in which the cells are independent but pressed together; there are tissues, like the muscles, in which the cells are extended into fibers.

Schwann summed up his findings by pointing out that every part of every animal or plant is made up either of cells or of the substances that are thrown off by cells; that, to some extent, cells have a life of their own; that the status of this kind of individual life depends upon the life of the organism as a whole.

The cell theory, established by the work of Schleiden and Schwann and sometimes called the Schleiden-Schwann theory, offers a logical and satisfying explanation of animal and plant structure and physiology. After this theory was once definitely stated, no one could successfully challenge it. It was modified in a good many details by later investigators. But the essence of the theory has remained unchanged since it was first formulated.

Out of the cell theory of Schleiden and Schwann arose the new science of cytology (the study of cells). The theory was also destined to influence profoundly many other biological sciences. For example, it revolutionized the science of embryology, which deals with the period of life between the fertilization of the egg and the moment of birth. The great name in the early development of this science is Karl Ernst von Baer (1792–1876); his treatise ON THE STORY OF THE DEVELOPMENT OF ANIMALS, published between 1828 and 1837, was long held in reverence by embryologists. Von Baer was the first to discover the eggs of mammals ripening in the ovaries and embedded in minute, fleshy nests called Graafian follicles. Examining the embryos of rabbits and dogs Von Baer showed how the specialized tissues of the growing animal are formed in regular and orderly fashion from the fertilized egg.

While Von Baer's work marked a great advance over previous studies in the field of embryology, he did not have a clear idea of the microscopic structure of tissues. He did not realize that tissues in their entirety are made up of cells or of the products of cells; nor did he realize that the eggs that give rise to tissues are cells. It was not until the findings of Schleiden and Schwann were adopted by researchers in embryology that this science was put on a firm basis. The first important work of embryology to utilize the cell theory was THE DEVELOPMENTAL HISTORY OF MEN AND ANIMALS, published by Albert von Koelliker in 1861.



Drawings showing the development of the embryo in a chicken egg, from Karl Ernst von Baer's *On the Story of the Development of Animals,* published in two volumes between 1828 and 1837.

The cell theory has become basic in many other sciences: in bacteriology, in pathology, in genetics and in histology, to name only a few. It is one of the great scientific generalizations of all time; it ranks with Newton's theory of universal gravitation and Mendeleev's periodic system of classification of the elements.

SCIENCE THROUGH THE AGES is continued on page 2908.

AN ELECTROMAGNET AT WORK

General Electric Co.

A 55-inch electromagnet loading machine-shop steel turnings in the salvage department of the General Electric Company's Erie works. The magnet can lift 850 pounds of scrap like this, on the average.

MAGNETS LARGE AND SMALL

What We Know and Do Not Know about Magnetism

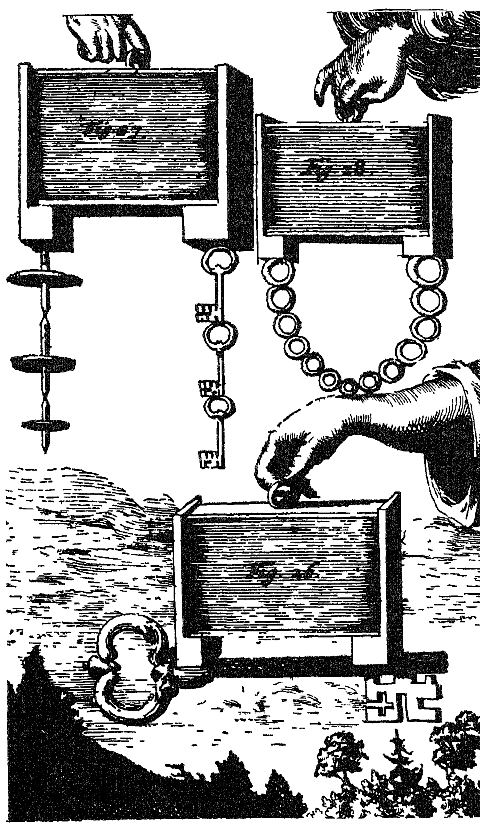
by
JOHN A. FLEMING

EVERYBODY is familiar with the toy magnet, that mysterious little U-shaped device that picks up needles or pins and that holds them indefinitely, through what seems to be sheer magic But the magnet is far from being a mere toy It is an essential part of a great many machines and tools and measuring devices, without which the world's work could not be done. A magnetized needle set within a compass helps the navigator to keep to his course at sea When you hold a phone receiver to your ear, a magnet records the vibrations set up by the voice of the person talking into the mouthpiece. The electric motor and the electric generator could not possibly work without their built-in magnets; neither could the ammeter, which measures the flow of current in the electrical system of an automobile.

Magnetism, the natural force that causes magnets to function as they do, revealed itself to men long centuries ago. A number of persons in antiquity knew that the black metallic iron ore called magnetite, or loadstone, had the property of drawing particles of iron to it. The Greek philosopher Thales (640?-546 B.C.) is said to have been the first to call attention to this property, but it may have been known long before. After Thales' time the loadstone was often mentioned in ancient writings; it was sometimes given the name of "magnet," from Magnesia, a district in Asia Minor where large magnetic deposits were to be found.

Socrates remarked that "the stone that Euripides calls a magnet . . . not only attracts iron rings but also imparts to them similar power of attracting other rings, suspended from one another, so as to form quite a long chain, and all of these derive their powers from the original stone." Lucretius, a Roman philosopher and poet of the first century B C. attempted to explain magnetism in terms of his atomic theory (See the article Inside the Atom, in Volume 1.)

There are many legendary accounts of the marvelous properties of magnets. The Arabian Nights contains the story of a ship



Loadstones attracting iron objects, as shown in a French treatise on the loadstone by D——, published in Amsterdam in 1687. The properties of the loadstone were known long before that time.

that approached an island made of magnetic rock; the ship fell completely to pieces because all the iron nails were pulled out of it through the attraction of the rock. Other ships, according to legend, avoided a similar fate by substituting wooden pegs for iron nails. There are stories, too, of huge statues of iron and bronze held in mid-air through the force exercised by magnetic domes.

Another tale gives a fanciful account of the origin of the word "magnet." It seems, according to this tale, that one day a shepherd called Magnes was tending his flock on the slopes of Mount Ida, in Asia Minor. Suddenly he noticed that the iron tip of his staff was being pulled toward the ground. He dug up the earth in the vicinity and found that his staff was being attracted by the loadstone in which the place abounded. Thereafter the loadstone was called a magnet in honor of the shepherd who had discovered it. Scholars have pointed out that this story originated long after the word "magnet" was in common use.

In the course of the centuries much of the mystery that once surrounded magnetism has been dispelled. In the place of out-and-out legends and pseudo-scientific speculation, we now have at our disposal a respectable amount of scientifically proved fact. Furthermore, we have been able to put the force of magnetism to work for us in a great many different ways.

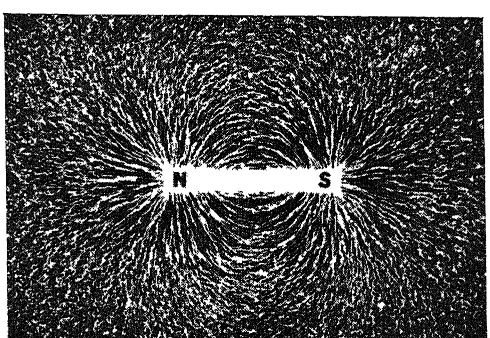
Today that natural magnet, the loadstone, no longer figures prominently in the study of magnetism or in its many applications, for practically all magnets nowadays are artificial. It is easy to make such a magnet out of a steel object, such as a needle, if you have a permanent magnet. Simply draw one end of the magnet along the needle, stroking in one direction only. The needle will become an artificial magnet and will have the property of drawing various particles to it. The original magnet has lost none of its strength; it will be capable of magnetizing any number of other steel needles. Suppose, now, that we break our magnetized needle in two; each of the fragments will be a magnet.

Until about 1820 artificial magnets were made by stroking bars of steel with a loadstone or with an artificial magnet. But then a Danish scientist, Hans Christian Oersted, revealed that a magnetic field can be produced by sending an electric current through a coil of wire, called a solenoid. If this wire is wound around a core of steel, the core will be permanently magnetized when current is passed through the coil. Nowadays the manufacture of artificial magnets is based on this principle.

Every magnet, natural or artificial, produces a magnetic field in the space around it. We can map out this field in various ways. If we place a magnet under a piece of paper whose surface is covered with iron filings, the filings will arrange themselves in lines of force like those shown in Figure 1. We can also use a small compass to mark out the magnetic field about a magnet. If we put the compass in different places in the vicinity of the magnet, it will assume the direction of the lines of force at any given point (Figure 2).

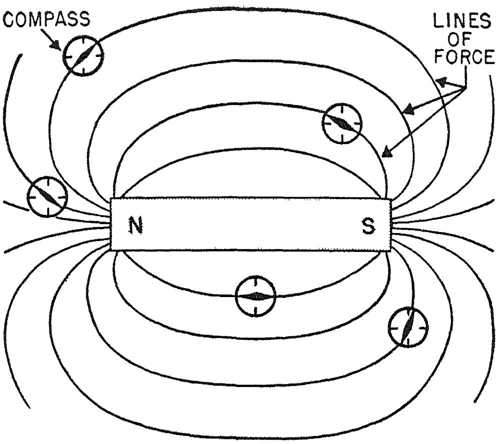
In any magnet there are regions near the ends of the long axis where the attractive forces are greatest. These regions are called the poles of the magnet; the line joining the two poles is the magnetic axis. If a straight, or bar, magnet is suspended so as to move freely in a horizontal plane, the magnetic axis will assume, roughly, a north-south direction.

The pole of a magnet that is directed northward is known as the north-seeking pole, or north pole or positive (+) pole.



From *Magnetic Phenomena* by S. R. Williams

1. Magnetic lines of force about a bar magnet. Iron filings on a glass plate that is laid over the magnet align themselves along the lines of force.



2. The magnetic field about a magnet may be marked out by a compass, which will assume the direction of the lines of force at any given point.

The pole that is directed southward is called the south-seeking pole, or the south pole or the negative (—) pole. Similar, or like, poles repel each other; dissimiliar, or unlike, poles attract each other.

When a bar magnet is bent double, it forms what is known as a horseshoe magnet. It will attract a given substance more powerfully than a bar magnet of corresponding size. The reason is that since the two poles are close together, the lines of force are crowded in a comparatively small space and exert a greater effect upon their surroundings.

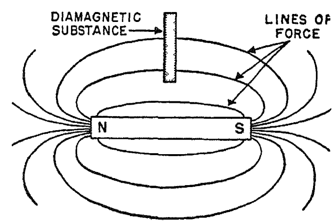
Magnets lose their strength when heated; but they regain it when they become cool again. However, if they reach a temperature that is known as the Curie point, they become entirely demagnetized. The Curie point for iron is about 750° C. (1382° F.); it is different for other magnetic materials. In general, magnets tend to lose their strength as they grow older. To provide longer life, they are aged: that is, they undergo various treatments by heat, shock and repeated magnetizations and demagnetizations in weak alternating fields.

Magnetic lines of force cannot penetrate certain materials as easily as they can penetrate air or a vacuum. Such materials are called diamagnetic ("magnetic across," in Greek) because rods made of these substances tend to take up a position *across* the field of force of a strong magnet (Figure 3). Bismuth, antimony and most of the other chemical elements are diamagnetic; so are their compounds.

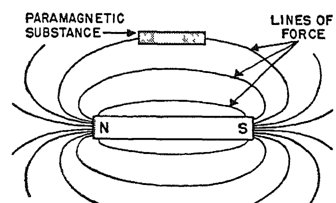
Magnetic lines of force can penetrate other materials more easily than they can penetrate air or a vacuum. Such materials are called paramagnetic ("magnetic alongside," in Greek) because rods made of them tend to line up *alongside* the field of force of a strong magnet (Figure 4). Iron and liquid oxygen are paramagnetic substances.

A few paramagnetic materials are so much more easily magnetized than the rest that they are generally put into a separate class, called ferromagnetic. The ferromagnetic materials derive their name from the fact that one of them is iron (*ferrum,* in Latin). Nickel and cobalt are also ferromagnetic; so are various alloys of these

3. The diamagnetic substance takes a position *across* the field of force.



4. The paramagnetic substance takes a position *along* the field of force.

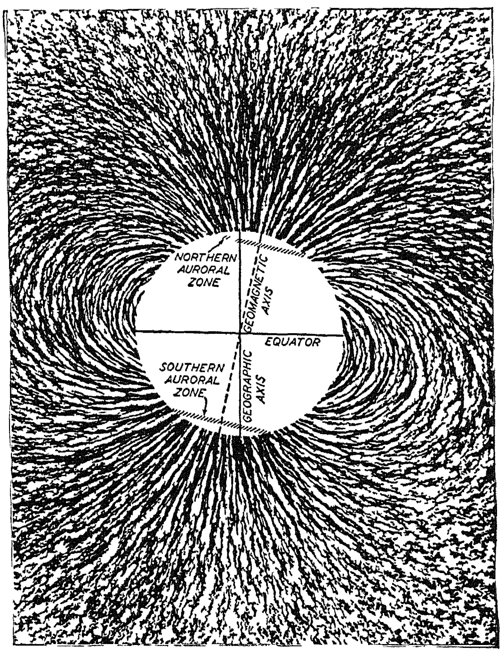


metals and a few other materials. Sometimes ferromagnetic substances are called magnetic materials, while all the rest are lumped together as non-magnetic materials.

Magnets that retain their strength for long periods of time are called permanent magnets. They have a wide range of uses in industry and in research. They serve in various measuring devices, such as ammeters, voltmeters, galvanometers, cardiograph recorders, seismographs (earthquake recorders), magnetic compasses, magnetometers and so on. They form an essential part of many kinds of scientific

equipment. Temperature, pressure and traffic signals are all controlled by permanent magnets. They are used in certain kinds of lathes, chucks, conveyors, hand tools and separators, and also in various toys and novelties.

Improvements in permanent magnets are constantly being made. New alloys with superior magnetic properties have been developed. Some of these alloys are called quench-hardening steels: that is, they are



Carnegie Institution of Washington

5. Magnetic field about the earth, represented by the alignment of iron filings along the lines of force on a glass plate laid over a disc magnet.

first heated to a very high temperature and then hardened by rapid cooling, after being "quenched" in water or oil. Quench-hardening steels include alloys of steel with carbon-manganese, tungsten, chromium, cobalt and cobalt-chromium. They all contain carbon, since steel is basically an alloy of iron and carbon.

Other alloys are carbon-free. They include alloys of aluminum-nickel-iron, aluminum-nickel-cobalt-iron (trade name, Alnico), aluminum-nickel-titanium-iron (trade name, Nipermag) and cobalt-molybdenum (trade name, Comol). All these substances require special casting, grinding, magnetizing and aging treatments.

Not all magnets are permanent. If electric current is passed through wire that is wound around a soft-iron core, the core will be magnetized but only as long as the current is turned on. If the current is shut off, the iron will lose practically all its magnetism; if the current is increased, the iron will have greater magnetic strength. This temporary sort of magnet — a core of soft iron set within a coil of wire through which an electric current is passed — is called an electromagnet.

The electromagnet is used in a great variety of modern electrical devices. It is the heart of the electric motor, and of such devices as the telegraph, the telephone and the electric bell. It serves to separate iron from its ores. Big electromagnets are frequently employed to load and unload iron and steel materials in railroad yards, steel plants and junk yards. Doctors sometimes use electromagnets to remove bits of iron or steel that have become imbedded in the eye.

We pointed out before that a magnet that is free to swing in a horizontal plane adopts, approximately, a north-south position. The reason is that it is attracted by magnetic forces arising within the earth itself. For the earth is a great natural magnet, with a North and South Magnetic Pole, a magnetic axis and a field of force that extends far out into space. Even four thousand miles above the surface of the earth, the magnetic intensity of this field is still one-eighth as great as it is at the surface. The lines of force of the earth's field are parallel to the surface near the equator; but as they approach the two magnetic poles, they bend and converge (Figure 5).

Certain substances within the earth — its magnetic deposits, for example — are highly magnetic; but that is certainly not true of most of the materials that make up our planet. As a matter of fact, a magnet of steel would be something like 10,000 times as powerful as one just as large made of typical earth-stuff. But in view of the earth's size, its total magnetism is pretty awe-inspiring. It is equivalent in effect to

that produced by 800 quintillion (800,000,-000,000,000,000,000) parallel one-pound magnets if they could be placed at the earth's center or if they could be evenly distributed through the body of the earth with one magnet for about every two cubic yards.

Naturally, if the earth is a huge magnet, other magnets will be influenced by it. The north-seeking pole of a bar magnet, moving freely in a vertical axis, will evidently be attracted to the earth's North Magnetic Pole. It is true that the North Magnetic Pole does not correspond exactly to the geographical North Pole, as we shall see; but if we make certain calculations, we can determine in what direction true north lies. Of course we can then find the other points of the compass. This is the principle of that supremely useful instrument, the magnetic compass.

The south-pointing chariots of the Chinese

The Chinese have been credited with the invention of the compass. It is said that the Emperor Hwang-ti, who lived twenty-five centuries before the birth of Christ, built a chariot on which a dummy, mounted on a pivot, always indicated south. By using this chariot at a time when a thick fog had closed in upon his army during a battle, Hwang-ti was able to defeat the foe. This account is almost certainly mythical. Unfortunately it is difficult to see how much truth there is in later Chinese accounts of south-pointing chariots.

A Chinese document of the third century A.D. contains a statement that a needle enables a ship to follow a southward course. But it is not until the twelfth century that we find in any Chinese work a detailed description of the manner in which a needle is made to point to the south. The invention of the compass has also been attributed to other peoples, including the Arabs, the Greeks and the Etruscans; but there has been no authentic proof of such claims.

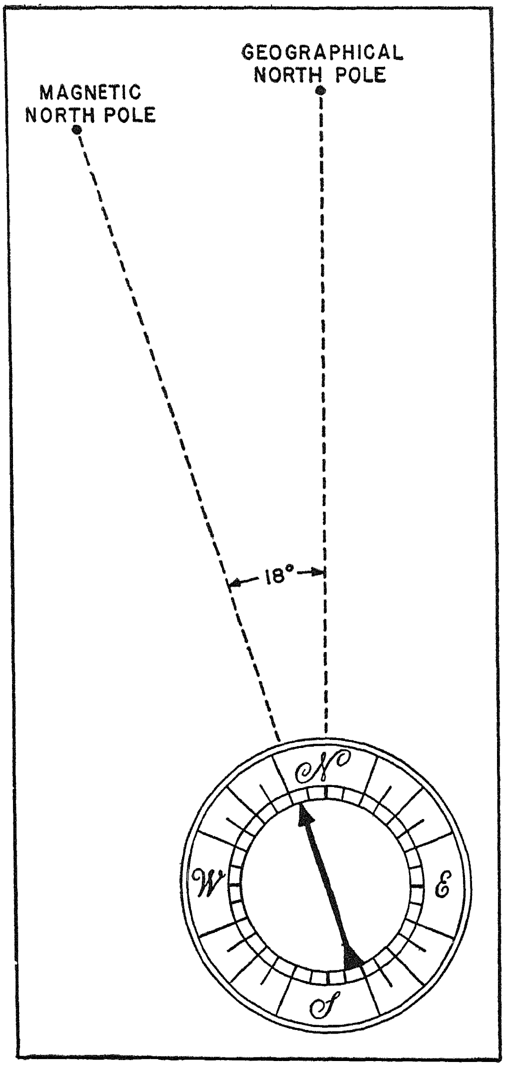
The earliest definite mention in European literature of the directive property of the magnet and its use in navigation appears in two Latin treatises by the Englishman Alexander Neckam. These treatises, entitled Of Instruments and Of the Nature of Things were written toward the end of the twelfth century A.D. The first of these works describes the use of the magnetic needle to indicate the north; Neckam points out that sailors use the needle to find their direction when the sky is overcast and the stars cannot be seen The second treatise gives a description of a magnetic needle mounted on a pivot.

An early authority on magnetism — Petrus Peregrinus

In the following century, Petrus Peregrinus de Maricourt, a soldier monk, discussed the directive property of magnets in his famous Epistle Concerning the Magnet. "Take a loadstone," he says, "and put it in a wooden cup or plate and set it afloat, like a sailor in a boat, upon water in a larger vessel, where it will have room to turn. Then the stone so placed in the boat will turn until the north pole of the stone will come to rest in the direction of the north pole of the heavens, and its south pole toward the south pole of the heavens. And if you move the stone away from that position a thousand times, a thousand times will it return by the will of God." Peregrinus suggested a number of improvements in the nautical compass.

In the years that followed, the magnetic compass was gradually perfected; but even the most learned had no idea why the needle always pointed in a more or less northerly direction. It was not until the year 1600 that the reason was definitely revealed.

In that year the learned English physician Sir William Gilbert published a treatise called Of the Magnet, Magnetic Bodies and That Great Magnet the Earth. This was one of the greatest scientific works of all time. In it Gilbert, who has been called the Galileo of magnetism, set forth his theory that the earth is a magnet, and that a magnetic compass needle points north because the north-seeking pole of the needle is attracted by the North Pole of the earth. Gilbert also pointed out that the Magnetic North and South Poles do not



6. The compass needle that is shown above points in a direction that is 18° west of true north; hence the declination of the compass is 18° west.

correspond to true north and south. He observed, too, that a magnetic needle free to move up and down dips toward the earth at many places. Gilbert's work laid the foundations for our present-day knowledge of the earth's magnetism.

We realize now that, as a result of the magnetic field surrounding it, the earth and its atmosphere constitute a great magnetic laboratory. In this, nature continually performs her experiments, utilizing as apparatus not only the earth, but also the sun, the moon and radiations from outer space.

The North and South Magnetic Poles are at quite a distance from true north and south — as much as a thousand miles, or even more. They are constantly shifting their positions. The Carnegie Institution of Washington has determined their average positions for various periods, as shown in the table at the top of the following page. This table indicates that both magnetic poles have shifted in a direction that is generally north by northwest.

The declination of the compass

Since the magnetic poles of the earth do not correspond to true north and south, it is very important to know how much they diverge; otherwise a navigation officer would have only an approximate idea of his direction. We can find out how great this divergence is by examining the declination of the compass. The declination represents the angle between the magnetic needle, as it points to the North Magnetic Pole, and the geographic meridian — that is, the line passing through a given point on the earth's surface and connecting the North and South Poles of the earth. If the declination is 12 degrees west at a given point, it means that here the compass needle points in a direction that is 12 degrees west of true north (Figure 6).

Another factor that is also important in many calculations is the inclination, or dip, of the compass. To determine this, a magnetic needle, called a dipping needle, is mounted on a horizontal axis and is allowed to swing in a vertical plane. The needle will follow the direction of the earth's lines of force. The dip of the needle represents the angle between the plane of the horizon and the magnetic needle (Figure 7). The dipping needle is vertical at the North and South Magnetic Poles; it is horizontal at the magnetic equator. It occupies intermediate positions between horizontal and vertical at other places on the earth's surface.

The degree of declination or inclination at different points on the earth's surface may be shown on charts (maps) showing

Ten-year period ending	*Position of North Magnetic Pole*	*Position of South Magnetic Pole*
1912.5*	71° N., 97° W.	71° S., 150.5° E.
1922.5	71° N., 97° W.	70° S., 149° E.
1932.5	72° N., 98° W.	69° S., 148° E.
1942.5	73° N, 98° W.	68° S., 146° E.

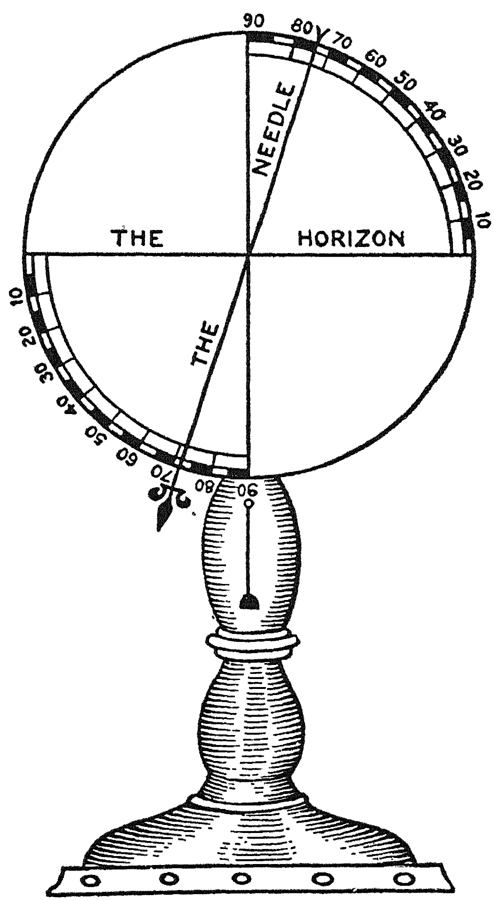
* Note. 1912.5 = halfway between the beginning and the end of the year 1912.

the entire world or a single region. In preparing a chart showing magnetic declination, the degree of declination is determined at a number of different places. A line is then drawn through all the points where the degree of declination is 0°; another, say, through the places where the degree of declination is 5° and so on. If this method were strictly followed and if the places where the declination is determined were spaced closely enough, it would be found that the lines would form an intricate pattern of complex bends and closed loops. It is customary to smooth out the lines somewhat and to disregard irregular values.

The same method is used in preparing charts showing magnetic inclination. The charts that show lines of equal magnetic declination are called isogonic (having equal angles); those that show lines of equal magnetic inclination are called isoclinic (dipping equally). Both isogonic and isoclinic charts are called isomagnetic. On pages 2708-09 we show a world isogonic chart.

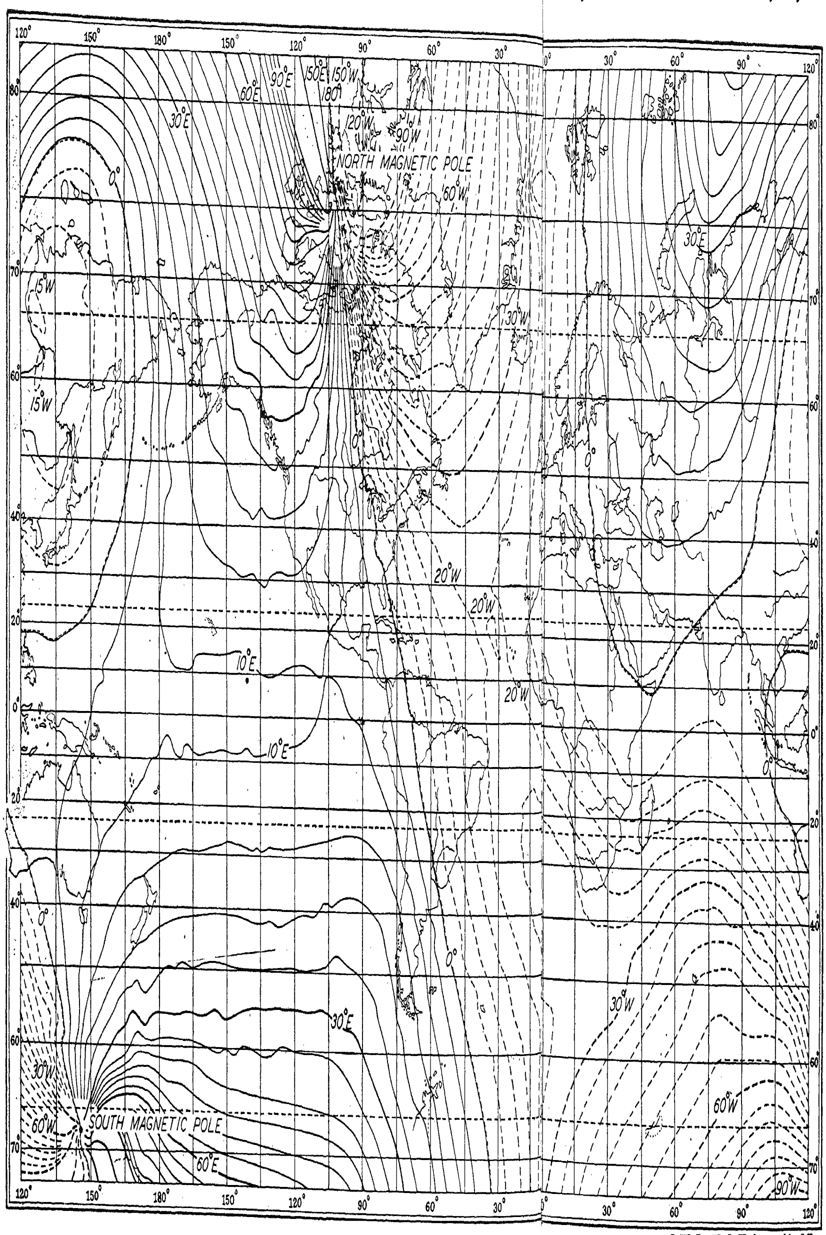
The usefulness of the magnetic compass has been enhanced with the development of the accurate isogonic charts that we have just described. It is true that on large vessels the gyrocompass is now the chief directional instrument. In all such ships, however, magnetic compasses are held in reserve. For, after all, the gyrocompass is dependent on a source of motive power for its operation and it is also subject to mechanical failure. The magnetic compass, on the other hand, practically never goes out of order and the only "power" that is required to run it is the attraction of the North Magnetic Pole.

There are certain more or less regular changes in the earth's magnetic field, known as secular variations. There are secular variations from place to place, from season to season, from Northern to Southern Hemisphere and, for the same place, from year to year. For example, observations made at London indicate that the



7. Sketch of the dipping needle with which Robert Norman measured dip at London in 1576. The needle, which was mounted on a horizontal axis, followed the direction of the earth's lines of force.

magnetic needle pointed 11° east of north in 1580 and 24° west of north in 1812. Since that time the needle point has shifted eastward and now points to about 10° west of north. All this indicates that this particular secular variation will complete a cycle in about five hundred years. The cycle of secular change varies from one place to another. Efforts have been made to predict such cycles on the basis of theoretical studies, just as astronomers predict eclipses of the sun and moon. It is now recognized, however, that because of the many unknown factors involved, there is as yet no basis for predictions of secular change. The fact is that secular variations have not only puzzled scientists for many years but are still an unsolved mystery.



World isogonic chart for the year 1945, showing the North and South Magnetic Poles and the lines of equal magnetic declination. The magnetic declination of the compass is the same for all points on a given line in the chart. Thus the declination is 10° E. in all localities through which the line marked 10° E. passes. Navigators find charts like this invaluable; without them, the compass reading would give only a rough idea of true north.

C. W. I.—U. S. Hydrographic Office

It has been found that as the earth revolves around the sun during the year, there are corresponding fluctuations in the earth's magnetic field. The maximum variations, or crests, occur during the equinoctial months of March and September, when the sun crosses the equator in its apparent yearly journey through the heavens. (See the article The Face of the Earth in Volume 1.) The minimum variations, or troughs, come in the solstitial months of June and December, when the sun is farthest from the equator in that same yearly journey.

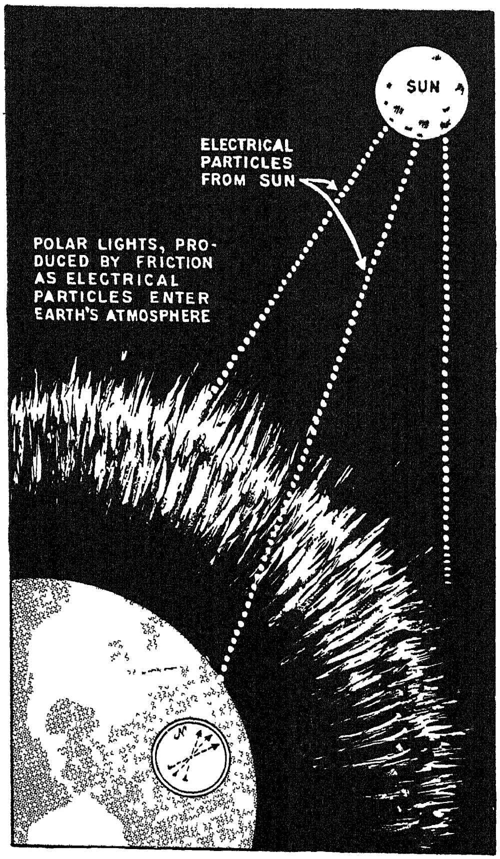
The presence of magnetic-ore deposits brings about anomalies, or irregularities, in the magnetic field of the earth. Such irregularities do not greatly alter the over-all picture of the whole field. They make it possible, however, to locate deposits of magnetic ores in a given area. Aerial surveys of the area are made with a magnetometer, an instrument for measuring the intensity and direction of magnetic forces. By examining the findings of such surveys, prospectors can determine the extent and depth of magnetic-ore deposits. In some cases, the soil and rocks may be only slightly magnetic, and there will be only minor anomalies in the earth's magnetic field.

Other variations in the earth's magnetism are caused by disturbances known as magnetic storms. These frequently occur simultaneously over the whole globe; they are much more violent in the polar regions because of the nearness of the earth's magnetic poles. There is not a regular cycle of quiet and disturbed days; an old disturbance may die out and a new one may occur at any time. Generally any marked disturbance in the magnetic field reappears in several successive months before it permanently disappears.

One of the principal factors in causing these magnetic storms is the existence of numberless electrified particles streaming from the sun. The earth's lines of magnetic force, extending far out into space, entrap these particles, which are made to travel in spiral paths around the lines of magnetic force. Since these lines are

steepest in the polar regions, the electrified particles penetrate most deeply in the earth's atmosphere in these areas. Not only do they bring about variations in the earth's field of force but they also cause the dazzling natural displays known as polar lights.

Polar lights result from the resistance offered to the electrified particles by the earth's atmosphere — a resistance that causes the particles to glow. These brilliant lights are known as the aurora borealis, or northern lights, when they occur in the Northern Hemisphere, and the aurora australis, or southern lights, when they occur in the Southern Hemisphere. By photographing auroras simultaneously from two stations which are a measured distance apart, it has been found that polar-light beams generally do not come closer than



The atmosphere's resistance to electrical particles streaming from the sun produces polar lights.

sixty miles from the earth's surface; they have been observed at heights above three hundred miles.

Observations in the United States and in various European countries have shown that there is a very close connection between sunspot activity and disturbances in the earth's magnetism. When the sunspots are the most active, there are the greatest variations in the earth's magnetic field and the most brilliant displays of polar lights.

Cosmic rays from outer space also contribute to magnetic variations. (See the article The Cosmic Rays, in Volume 7.)

Thus far we have dealt with the effects of magnetism and with its numerous applications. The question now arises: what is the ultimate cause of magnetic fields of force and of polarity? Thus far the scientists have not been able to give a definite answer. It is quite generally agreed that magnetism results from the orderly arrangement or interaction of particles of matter within magnetic materials. According to one theory the molecules in such substances are tiny magnets. When they are all jumbled together within a given substance, pointing every which way, the magnetic forces involved cancel each other and the substance is not a magnet. But if the wee molecule-magnets are lined up so that all their north poles point in one direction and all their south poles in the opposite direction, the substance becomes a magnet with a north pole at one end and a south pole at the other.

Other scientists believe that the basic units in magnetic phenomena are not molecules but much smaller particles — the electrons that revolve about the nuclei of atoms and that also spin about their own axes. According to this theory, the manner in which the electrons revolve and rotate accounts for the various magnetic effects.

None of the theories that have been advanced have provided a satisfactory explanation of the why and wherefore of magnets. When such an explanation is forthcoming, it will go far toward solving some of the problems that still baffle the students of magnetism.

COMPANIONS OF THE SUN

What Recent Observations Have Revealed Respecting Mercury and Venus

THE PLANETS INSIDE THE EARTH'S ORBIT

WE have already given some consideration to the vast cosmic processes by which our solar system is believed to have come into being. Let us now examine more closely the several planets and their satellites, the asteroids or minor planets, and the comets, and meteors or shooting stars, which also belong to the system, in order that we may return with more detailed knowledge to a brief review of their entire history. Knowledge of the individual planets has greatly increased within recent years, and has revealed a diversity which was previously quite unsuspected; yet that very diversity has done more than anything else to throw into relief the dynamic unity of the system and the orderly development of its individual members in accordance with fixed laws.

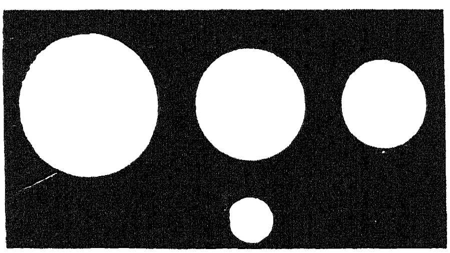
Mercury, the nearest of all the planets to the sun, is for that very reason not easily seen. Copernicus, the founder of modern astronomy, who was the first to lay down the principle that the earth and other planets revolve round the sun as their center, lamented before his death, in 1543, that he had never been able to catch a glimpse of this innermost planet. Probably the reason for his failure to see it is to be found in the nature of the district where he lived, the low and misty region of eastern Prussia, where the Vistula flows into the Baltic. Otherwise, one so deeply interested in the planets would certainly have seen Mercury at some time, because six times a year about two months apart, the planet can be seen for several days as a first-magnitude star. Spring and autumn are the best times.

Sometime in the spring, for about two weeks, it is seen after sunset near where the sun goes down. In the autumn, for two weeks, it appears just before sunrise. It is never more than two hours away from the sun, and is hard to see. Mercury has been known from the earliest times, and because of its appearance sometimes in the east and sometimes in the west, it was from the first very naturally regarded as two separate stars, a morning and an evening star, and was thus represented under two names in the mythologies of Egypt, India and Greece.

In spring, which is the more convenient season for us to watch it, Mercury is first observed very soon after sunset. Night after night, when the twilight deepens enough to show the stars, it is seen to appear higher in the sky, and night after night it increases in brilliancy. Then the contrary process sets in; night after night Mercury follows the sun more quickly over the horizon, and at the same time its luster diminishes. The course of its autumnal appearance as a morning star is closely similar; at first it is not very brilliant, and is seen very shortly before sunrise; then it gains in brightness and appears daily earlier before the sun; and then the process is reversed — it approaches the sun and becomes fainter day by day.

If Copernicus had lived later, he would surely have seen Mercury, for it is a hard object only for the naked eye. With the telescope this planet, like other luminaries, can be seen all round the year, and high in the sky in broad daylight. The telescope shows also that the disc of Mer-

cury has phases like those of our moon, increasing from a thin crescent to a full circle, decreasing again to a crescent, and then disappearing altogether when the planet is nearly between the earth and the sun Mercury and Venus, being within the earth's orbit, are alone among the planets in showing the full cycle of these phases, Mars periodically shows the gibbous phase like the moon a few days before or after full, but never becomes a crescent, and we see the discs of the other outer planets always fully illumined The mean distance of Mercury from the sun is 36,000,000 miles, at perihelion, or the nearest point of its orbit to the sun, it is 28,500,000 miles away, and at aphelion, or the furthest point of the orbit, is 43,300,000 miles Mercury has, therefore, an orbit which is far more elliptical than



SUN SEEN FROM MERCURY AND THE EARTH
The comparative sizes of the sun s disc as seen from Mercury at its least, mean and greatest distances and also (below) as seen from the earth

that of the other planets, which are indeed elliptical, yet so slightly so as to be hardly, if at all, recognizable in a diagram

The eccentricity of the orbit is so great that sometimes Mercury is only two-thirds as far from the sun as it is at other times In consequence, the angular diameter of the sun's disc, as seen from Mercury, must vary greatly As seen from earth the sun subtends an angle of 32′, but at the distance of Mercury the angular diameter varies from 67′ at aphelion to 104′ at perihelion That is to say, the sun's disc as seen from Mercury has at least more than four times the area, and at most more than nine times the area, that it has when seen from earth, and consequently the heat received by Mercury must exceed from four to nine times that received, area for area, on the earth's surface

Mercury completes its orbit in almost exactly 88 days, so that this planet runs through rather more than four of its years to one of ours The velocity of its movement along its orbit varies considerably according to its distance from the sun Thus, Mercury travels at 23 miles per second at the remotest part of its orbit but attains a speed of 35 miles per second where its path lies nearest to the sun The mean velocity is 29 miles per second and at that rate Mercury moves through the distance of its own diameter in about two minutes The distance of Mercury from the earth varies from 50,000,000 miles, when the planet's disc has an apparent diameter of 13″, to 136,000,000 miles, when the diameter of the disc decreases to $4\frac{1}{2}''$

Mercury was long supposed to rotate upon its own axis about as fast as the earth does, and so to have a day of about twenty-four hours But Schiaparelli who was the first to undertake the systematic study of the planet during the hours of daylight, concluded from his extended observations of the markings on its surface that Mercury's day equals 88 of our days and this conclusion was confirmed by Lowell's observations at Flagstaff In the case of this planet, therefore, the day and the year are of equal length

As our moon rotates once on its own axis in the course of its revolution round the earth, so that it keeps always the same face turned towards us, so Mercury always presents the same face to the sun The cause of the fixed aspect is doubtless the same in both cases The tides raised in Mercury by the gravitation of the sun have long ago by their friction brought to an end the planet's rotation relatively to the sun

One hemisphere of Mercury is therefore exposed incessantly to the fierce heat of the sun, while the other hemisphere is forever exposed to the frigid night of outer space As is not the case with our moon, there is on Mercury a narrow belt of land on either side, lying between the hemisphere of day and the hemisphere of night where there are alternate day and night, sunrise and sunset

MIDNIGHT SUN OVER TORNE LAKE

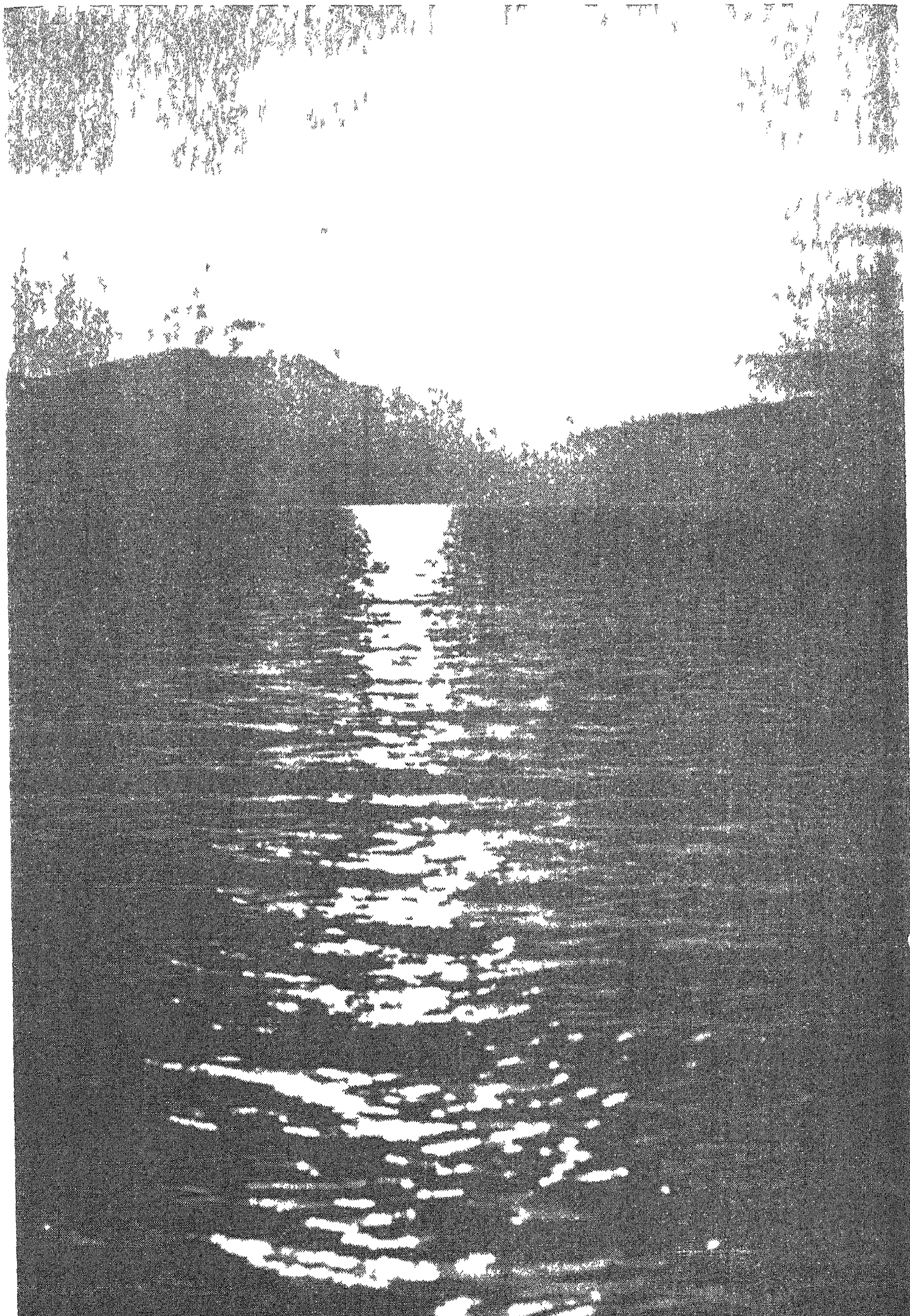


Photo Swedish Travel Information Bureau

WHERE THE SUN SHINES AT NIGHT AS WELL AS BY DAY

This narrow belt, about $23\frac{1}{2}°$ in width, of changing light and darkness, is due to the highly eccentric form of the orbit. In order that the planet might keep always exactly the same face to the sun, while pursuing such an orbit, it would have to rotate at varying speeds upon its own axis, turning now somewhat slower and now somewhat faster. But the speed of its rotation being constant, its face is turned not always absolutely to the sun, but sways now slightly forward, along its orbit, and again slightly backward. The axis about which Mercury rotates is not inclined to the plane of its orbit, as in the case of the earth, but is vertical. The planet therefore has no seasons, except such as may be caused by the wide variation in the apparent size of the sun's disc we have already mentioned. Mercury has a diameter of about 3400 miles. It is not accompanied by any satellite.

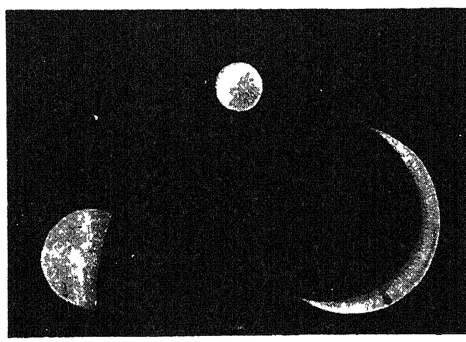
The phases of the planet are not visible to the unaided eye; the telescope is needed to enlarge the brilliant point of light into an image of disc or crescent. With a powerful instrument and good atmospheric conditions, the terminator, or line separating the bright from the dark portion of Mercury's globe, is seen to be very irregular, as it is in the moon, showing that Mercury's surface, like hers, is highly mountainous.

Mercury shows no trace of an atmosphere, the bright and dark portions of the disc being sharply separated without any twilight. In this respect, as in others, Mercury resembles our moon in being a dead world. Its surface is closely comparable to that of the moon with regard to their respective power of reflecting light. As a reflector, Mercury is far inferior to Venus.

The markings on the face of Mercury were minutely studied by Lowell at Flagstaff, and, as mapped by him, they present a very definite and remarkably geometrical appearance. He suggested that "they seem to mark a globe sun-cracked. At such a condition the curious criss-cross of dark, irregular lines certainly hints, accentuated and perfected as it is by a bounding curve where the mean sunward side terminates. Though they cannot probably be actual cracks, however much they may resemble such, yet they may well owe their existence to that fundamental cause."

The transit of Mercury or of Venus is the passage of the planet between the earth and the sun, so as, from our point of view, to cross the face of the sun.

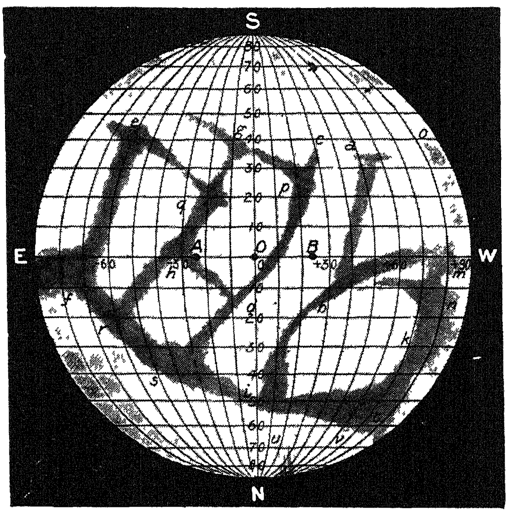
Of course, only these two planets, having orbits within that of the earth, can ever pass over the sun's disc. If Mercury's orbit were in the same plane as that of the earth there would be three transits in the year, because the inner planet revolves four times round the sun in a year, while the earth revolves once round the sun in the same direction. But the orbit of Mercury is inclined by about



MERCURY AS SEEN AT ITS GREATEST, MEAN AND NEARLY ITS LEAST DISTANCE

seven degrees to the ecliptic — that is to say, to the plane of the earth's orbit; and Mercury therefore crosses the ecliptic twice in eighty-eight days, but is usually either above or below that plane. A transit of Mercury can only take place when the planet is between the earth and the sun, and happens also to be crossing the ecliptic. These two conditions coincide from time to time at unequal periods, as follows — three years, ten years, three years, thirteen years, seven years, ten years — and then the same cycle recurs again and again indefinitely. Thus recent and coming transits of Mercury are in the years 1878, 1881, 1891, 1894, 1907, 1914, 1924, 1927, 1937, 1940 and 1953. All the transits of Mercury are either in May or in November. The transit of November, 1953, will be completely visible here.

The transit of Mercury was first foretold by Kepler, in 1627, for November 7, 1631; and a few hours after the moment which Kepler had predicted, Gassendi, the French philosopher and mathematician, watching an image of the sun projected into a dark room, saw the black globe of the planet entering upon the sun's disc. Since that date the transits of Mercury and of Venus have been carefully observed as astronomical events of the first importance. Their scientific value is manifold. They afford an opportunity of checking very exactly all calculations with regard to the orbits of these planets; special observations may be made of the dark planetary globes when silhouetted against the bril-



THE MARKINGS ON MERCURY

liant background of the sun's image; and the transit of Venus in particular has been used to determine the astronomical unit in terms of which all measurements of distance within the solar system are expressed.

Like Mercury, the planet Venus is at times an evening star, appearing after sunset, and at other times a morning star, appearing before sunrise, and was therefore known in antiquity under two names, Hesperus and Phosphorus. Like Mercury also, as an evening star it rises higher night after night, increasing in brilliancy, and then returns night after night towards the sun; and as a morning star it daily precedes the sunrise by a longer interval, and then daily this interval diminishes again. But its orbit is much larger than that of Mercury, so that Venus may rise as long as four hours before the sun, and set four hours after it.

After the sun and moon, Venus is by far the most brilliant luminary in the heavens. At its brightest it is more than fifty times as bright as any other star in our sky; it throws by night a distinct shadow; and by day, if one knows where to look for it, and the atmosphere is favorable, Venus may be seen with unaided vision in full daylight.

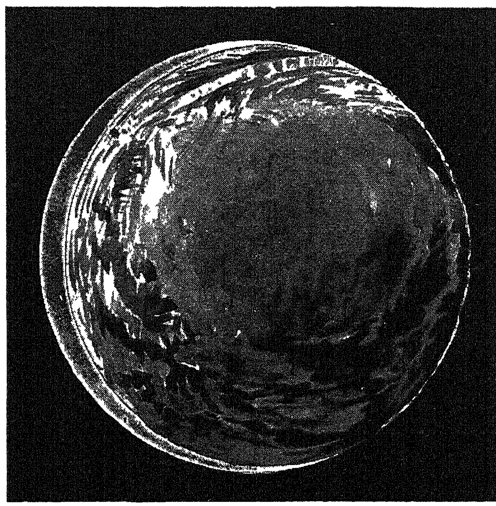
Being within the orbit of the earth, Venus has phases like those of Mercury and the moon These phases are invisible to the unaided eye, to which the planet always appears as a point of light, but they may be seen with a telescope of no great power. They were among the first discoveries of the telescope, having been seen by Galileo in September, 1610. Anxious to secure the merit of the discovery without risking his reputation by publishing before he had made sure of it Galileo sent out an anagram, the letters of which could be transposed into a Latin verse announcing the phases of Venus. The phases are best studied in daylight, because of the great brilliancy of the planet by night. Venus is very much larger when seen as a crescent in that part of its orbit which is near to earth than when seen as a full disc at the other side of its orbit. At its extreme distance the disc has an angular diameter of nine seconds, but at its nearest point the crescent has a diameter of over sixty seconds. This extraordinary variation in its apparent size is accounted for by the great difference between the distances from earth to Venus when the latter is at the nearest and at the furthest points of its orbit; when nearest to earth, Venus is 26,000,000 miles away, but when furthest it is at a distance of 160,000,000 miles.

The orbit of Venus is very nearly circular, and has almost no eccentricity. The planet revolves about the sun once in about 225 days — that is to say, in about seven and a half months. Venus is very nearly the same size as the earth, having a

diameter of 7575 miles as compared with earth's mean diameter of 7918 miles. The axis about which Venus itself rotates is almost vertical to the plane of its orbit. In the seventeenth and eighteenth centuries it was reported again and again that Venus had a satellite, but as no evidence of this moon has been seen with the far more powerful telescopes of later date, it is believed that these earlier accounts were due to imperfections of the instruments then in use, or to want of familiarity with certain optical illusions, or "ghosts", which are incidental to all telescopic observation.

The planet Venus has an atmosphere to which by far the greater part of its brilliancy is due. Evidences of this atmosphere are manifold. Thus twilight, which is always and everywhere due to atmosphere, is seen along the inner curve of the planet's crescent, and prolongs the points or cusps of the crescent beyond the semicircle. Examination of Venus' light with the spectroscope can show us only the elements present in the upper atmosphere of that planet, and not in the lower reaches of the atmosphere. While it was formerly believed that Venus had an atmosphere much like that of the earth, we know today that there is a great difference. We find there no actual evidence of either water or free oxygen. There is a great deal, however, of carbon dioxide in the upper atmosphere. This fact has led some astronomers to believe that there must be plant life on our near neighbor's surface. It is quite impossible at the present time to tell whether oxygen and water vapor might exist in the lower part of the atmosphere.

On the occasions of its transit, when Venus enters upon the sun's disc, the outer portion of its dark globe, which has not yet crossed the edge of the sun, is plainly outlined by a ring of light, due to refraction of the sunlight by means of the planet's atmosphere. From the extent to which it refracts light, it has been estimated that the atmosphere of Venus is nearly twice as dense as that of earth. But the most remarkable evidence of this atmosphere is shown when the planet approaches what is known as inferior conjunction — that is to say, the point of its orbit at which it is between the earth and the sun. If it should happen at the same time to be on the plane of the ecliptic, it will then, of course, cross the sun's disc, and be visible as a black globe. But in the great majority of cases, when Venus is in inferior conjunction, it is either above or below the ecliptic, and would thus be invisible, as the new moon is invisible, except for the presence of an atmosphere. When followed by the telescope to this position, the crescent of the diminishing Venus becomes narrower and narrower, and then flows right round the dark disc, so that the entire profile of the planet is outlined by a ring of sunlit atmosphere.

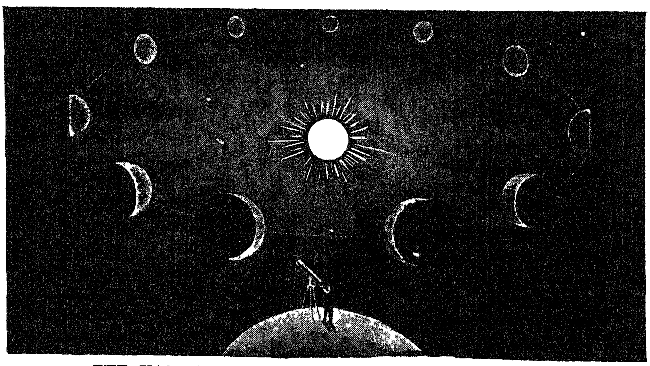


THE LIGHT WITHIN THE CRESCENT OF VENUS

Just as the unilluminated disc of the moon, usually invisible within its crescent, is often seen to gleam faintly with earth-reflected light, presenting the appearance known as "the old moon in the young moon's arms", so the dark portion of the disc of Venus sometimes shines dimly with a light which cannot be derived immediately from the sun, showing a pale, ashy gleam over all the surface which is embraced by the vivid silver of the crescent.

This appearance is not easily explained, but there is no lack of theories intended to explain it. Observing that this faint illumination of the night side of Venus has sometimes a violet tinge, and that

the years in which it has been most noticed have corresponded to some extent with those in which the aurora borealis has been exceptionally active on earth, some have persuaded themselves that we witness from time to time displays of the aurora in Venus. Others consider that the general light of the stars, reflected from the clouds and atmosphere of Venus, is sufficient to account for this ghostly glimmer. Others, have boldly suggested some kind of phosphorescence of the planet's surface. Newcomb pointed out that the phenomenon is only seen in the daytime or in bright twilight, and rarely or never after dark, and dismissed it as due to some unexplained optical illusion. "Such an illumination," he says, "would be far more easily seen by night than by day, because during the day an appearance easily seen at night might be effaced by the light of the sky. If, then, the phenomenon is real, why is it not seen when the circumstances are such that it should be most conspicuously visible?"



THE VARYING PHASES OF VENUS AND MERCURY

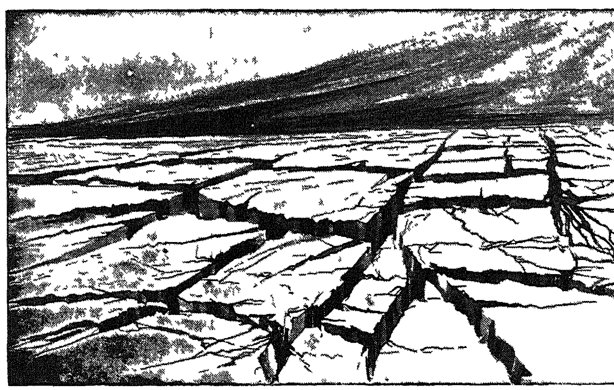
Lowell, believing for other reasons that the night side of Venus is covered with ice, applied that theory to explain its elusive glow. "If the night hemisphere of Venus," he suggests, "be one vast Polar sheet, we have there a substance able to mirror the stars to a ghostlike gleam which might be discernible even from our distant post." So we have free choice of conjectures in the matter.

The extraordinary brilliancy of the planet's illumined surface is more easily accounted for. Venus is so near the sun as to receive about twice the amount of light on its surface that we receive on earth; it is also near to the earth, so that the reflecting surface is large from its proximity. It is brightest when it has approached so near the earth that its illumined crescent occupies only one-fourth of the area of the disc. But the brightness of Venus is chiefly due to the nature of the reflecting surface. Area for area, Venus is five times as bright as Mercury, although Mercury is far nearer to the source of light.

It is estimated that Venus returns almost nine-tenths of the light which falls upon its surface, being thus an even more perfect reflector than white clouds, which reflect little more than seven-tenths of the light which they receive. This unusually effective reflecting surface is the planet's atmosphere. It was formerly believed that Venus was wrapped in an envelope of clouds, and that these gleamed in the sunlight with such brilliancy as to distinguish this planet above all other stars for brightness. But it is now known that, bright as they are, clouds are yet not nearly bright enough to give the reflected light which we receive from Venus.

It was believed until recent years that Venus rotated on its own axis in somewhat less than twenty-four hours, and this view was supported by observations which appeared to be very exact, though more recent study seems to overthrow them altogether. As early as the seventeenth century, Cassini distinguished a bright spot on the planet's surface, and, following its movements, concluded that the day of Venus was of nearly the same length as the terrestrial day. Towards the end of the eighteenth century Schröter came to a similar conclusion. He found that one of the points of the planet's crescent was blunted at intervals of rather more than twenty-three hours, and considered that this effect was due to the daily return of some mountainous elevation to that point.

Again, in the nineteenth century, the same period of rotation was affirmed by De Vico, on the basis of a study of certain markings which he thought he observed on the face of Venus, and their apparent daily movements. But many astronomers were never able to distinguish definite and permanent markings of any kind, and were inclined to agree with Herschel that Venus was wrapped in clouds which hid the features of the surface and prevented any trustworthy observations of its rotation. It is now fairly certain that both of these views were mistaken. Venus does not rotate in a way which is at all comparable to that of our earth, and the astronomers who witnessed that rotation were unconsciously influenced by what they expected to find. Today astronomers believe that Venus rotates on its axis in a period of a few weeks, probably about thirty days. It is almost impossible to determine this accurately, however, since Venus is surrounded by heavy bands of white clouds.



AN IMAGINARY LANDSCAPE ON THE SUNNY SIDE OF VENUS
It is thought that this side of Venus has a surface cracked by heat, and swept unceasingly by wind and dust storms of appalling velocity.

Schiaparelli, whose observations led to the adoption of the view that the aspect of Mercury remains fixed, was the pioneer in the case of Venus also. Finding certain definite markings on the planet, he watched them intently day by day, and found that their position remained constant, or so nearly constant that the period of the rotation of Venus could hardly be shorter than the period of its revolution round the sun. Similar observations, made by Lowell and his assistants in Arizona, not only confirmed Schiaparelli's conclusions, but threw new light on the markings of Venus. The planet was examined under better conditions of observation than ever before, with the result that the details of its surface came out with unprecedented clearness. Instead of isolated points, distinguished by their greater brightness or darkness from the surrounding surface, Venus now showed a very remarkable system of faint but perfectly definite and constant straight streaks, or lines, across its face, in a notably geometrical arrangement. By observation of these, it was soon possible to affirm that the period of the planet's rotation on its own axis coincides with the period of its revolution round the sun. The constancy of the markings showed, further, that they are not forms of cloud, and their clearness revealed that Venus is not, as had been thought, wrapped in a cloud-mantle.

The most characteristic markings are radial streaks which run inwards from the circumference of the planet's disc toward its center; they are broad and definite at the circumference, but become fainter, narrower and less clearly defined as they converge. Lowell believed these streaks to be marks of wind currents in the atmosphere. He explains them thus:

"One face baked for countless æons, and still baking, backed by one chilled by everlasting night, while both are still surrounded by air, must produce indraughts from the cold to the hot side of tremendous power. A funnel-like rise must take place in the center of the illuminated hemisphere, and the partial vacuum thus formed would be filled by air drawn from its periphery, which, in its turn, would draw from the regions of the night side. Such winds would sweep the surface as they entered, becoming more superficial as they advanced, and the marks of their inrush might well be discernible even at the distance we are off. Deltas of such inroad would thus seam the bounding circle of light and shade."

The theory is ingenious, but it would be more convincing if there were not other linear markings, not differing in appearance, which do not follow the radial direction. These tremendous wind currents, however, must continually sweep the surface of Venus; and it is difficult to resist the further conclusion, suggested by Lowell, that their effect will be to take up all the moisture on the sunward side of the planet and deposit it in the form of snow and ice upon the dark side.

Recent studies of Venus, which are necessarily limited to regions of the atmosphere above the dense Venusian clouds, have shown neither oxygen nor water vapor, but do show much carbon dioxide. Rupert Wildt has suggested recently that the clouds of Venus may contain some formaldehyde. If this theory is correct, life as we know it would seem to be impossible on Venus.

Like the planet Mercury, though much more rarely, Venus crosses the face of the sun. As we have seen, it completes its annual revolution in 224.7 days, but the earth is revolving round the sun, though more slowly, in the same direction; so that Venus is in inferior conjunction — that is to say, comes between the earth and the sun only once in every 584 days. Transits of Venus would therefore occur once in about every nineteen months, if Venus were always in the plane of the ecliptic. But the plane of its orbit is inclined by more than three degrees to the ecliptic, so that when the planet comes into inferior conjunction it is generally either above or below the ecliptic. Four times, however, in every 243 years Venus is at the same time on the plane of the ecliptic and in inferior conjunction with the sun, and there is a transit.

These transits always take place in June or in December but at irregular intervals, namely, 121½ years, 8 years, 105½ years, 8 years; after which the cycle is again repeated, and so on. It will be noticed that the first period is equal to the sum of the other three. A transit of Venus is plainly a rare event; the last took place on December 6, 1882, and the next will be on June 8, 2004.

The rare transits of Venus an astronomical event of great importance

The transit of Venus must always remain an astronomical event of great interest, though it has not now the same unique importance it used to have, because more exact means have been devised for determining the distance of the sun from the earth. Thus, the effects of the sun's gravitation upon the moon, and again the time which light takes to travel from the sun to the earth, are now used for the calculation of the sun's distance from us. Before these methods were thought out, however, astronomers were dependent principally upon the transit of Venus for this very important measurement.

How astronomers calculate the distance of the sun from the earth

The method used in these observations may be briefly explained as follows.

Let us imagine that two observers, one of whom is situated as far north as possible on the earth's surface, and the other is situated as far south as possible, are watching the same transit of Venus. It is obvious that the northern astronomer will see Venus sail across the sun's disc along a lower line, and the southern astronomer will see it cross higher up the disc; and, of course, these two lines will be parallel to one another, and near together, on the sun's disc. One of these lines will be longer than the other, because it will cross the disc at a wider part. Viewed from one of the stations on the earth, the transit of Venus will occupy a longer time than it will occupy when viewed from the other station. From the difference of the periods which the transit has taken at the two stations, together with a knowledge of the distance between the two stations, it is possible for mathematicians to calculate the distance of the sun from the earth.

In order to observe the transits of Venus in 1874 and again in 1882, astronomical expeditions were sent out by all the more advanced nations to every part of the world from which these transits could be seen, but with only partial success.

THE RETURN OF THE WATERS

Sources, Tracks, Windings, Vagaries,
Volume, Color, and Taste of Rivers

DISTRIBUTION OF THE CHIEF RIVERS

RIVERS may be defined as streams of fresh water of considerable size which run downhill, and ultimately flow either into the sea or into an inland lake. The water is, directly or indirectly, rain or melted snow. Again, it is vapor from the sea that makes the rain and snow. And so we have a constant circulation of water — sea, rain, river, sea, rain, river — "into the place from whence the rivers come, thither they return again".

Looking at the matter in another aspect, we may say that a river is a result of evaporation, condensation and gravity. The water vapor evaporated from the sea is condensed into rain, and the rain, falling upon the irregular land, is gathered together into certain channels by gravity, and led downwards to the sea again. Here we see one of the many missions of the mountains. The cold, rough hands of the mountains it is that clutch the clouds and condense the rain; the mountains it is that give gravity its opportunity and determine the direction of the water's flow. Wherever there are mountain ranges we have cold condensing surfaces; and where the peaks are snowy or icy their efficacy as condensers is naturally increased. Well known are the cloudcaps that so many mountains wear, and the cloud-banners that stream away from snowy or icy peaks when a wet wind blows.

With his customary eloquence, Ruskin describes the relationship of mountain and river: "Every fountain and river, from the inch-deep streamlet that crosses the village lane in trembling clearness, to the massy and silent march of the everlasting multitude of waters in Amazon or Ganges, owe their play and purity and power to the ordained elevation of the earth. Gentle or steep, extended or abrupt, some determined slope of the earth's surface is of course necessary before any wave can so much as overtake one sedge in its pilgrimage; and how seldom do we enough consider, as we walk beside the margins of our pleasant brooks, how beautiful and wonderful is the ordinance — of which every blade of grass that waves in their clear waters is a perpetual sign — that the dew and rain fallen on the face of the earth shall find no resting-place; shall find, on the contrary, fixed channels traced for them from the ravines of the central crests down which they roar in sudden ranks of foam to the dark hollows beneath the banks of lowland pasture, round which they must circle slowly among the stems and beneath the leaves of the lilies; paths prepared for them by which, at some appointed rate of journey, they must evermore descend, sometimes slow, and sometimes swift, but never pausing; the daily portion of the earth they have to glide over marked for them at each successive sunrise; the place which has known them knowing them no more; and the gateways of guarding mountains opened for them in cleft and chasm, none letting them in their pilgrimage, and from afar off the great heart of the sea calling them to itself: 'Deep calleth unto deep'!"

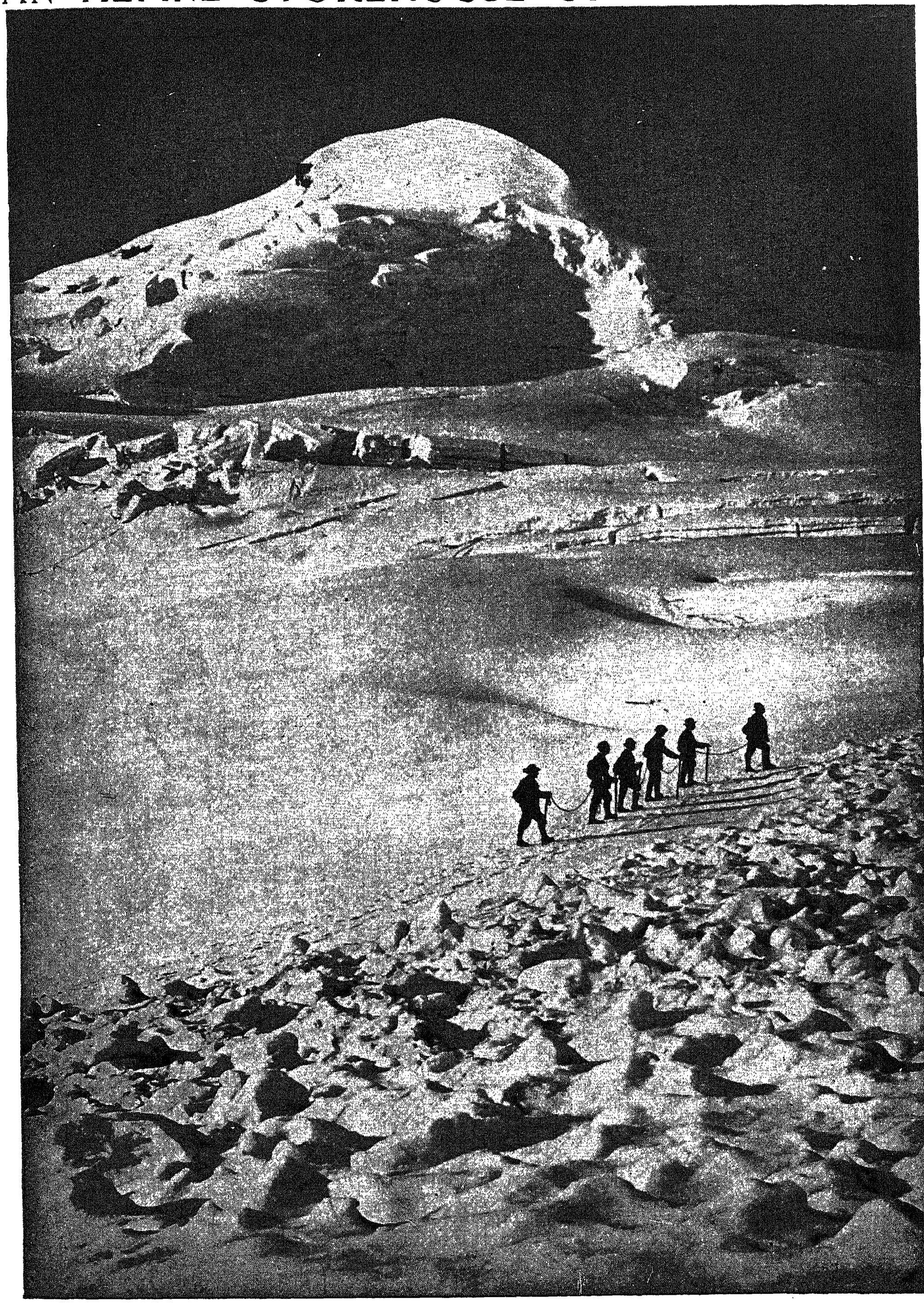
But the mountains do more than gather and condense rain to make rivers; they also store it. When man wishes to store water he builds huge tanks and reservoirs, but when nature wishes to store water

she collects it in spongy mountain marshes and boglands, or she freezes it into snow and ice. Snow and ice especially are nature's contrivance to build up a reserve of water against summer drought. All winter, when the rainfall is heavy, she piles up enough snow and ice to make cataracts in the spring, and to irrigate the lowlands in the summer. The same sun she used to lift the water she uses to thaw it. In the summer many rivers would be dried up just when most needed were it not for this cold storage.

SUNSHINE ABOVE AND RAIN BELOW — A CLOUD THAT CONDENSES ON MEETING A MOUNTAIN

In every country and continent it will be found that there are elevated lines and mountain ranges which produce slopes in opposite directions, and thus direct the course of running water either one way or another, more or less after the manner of the ridge and pitch-roof of a house. These directive elevations are known as watersheds, or divides. A watershed, or divide, is indeed the intersecting line of two divergent slopes causing diverging rivers; though the term watershed is also used to designate the entire slope.

AN ALPINE STOREHOUSE OF THE WATERS



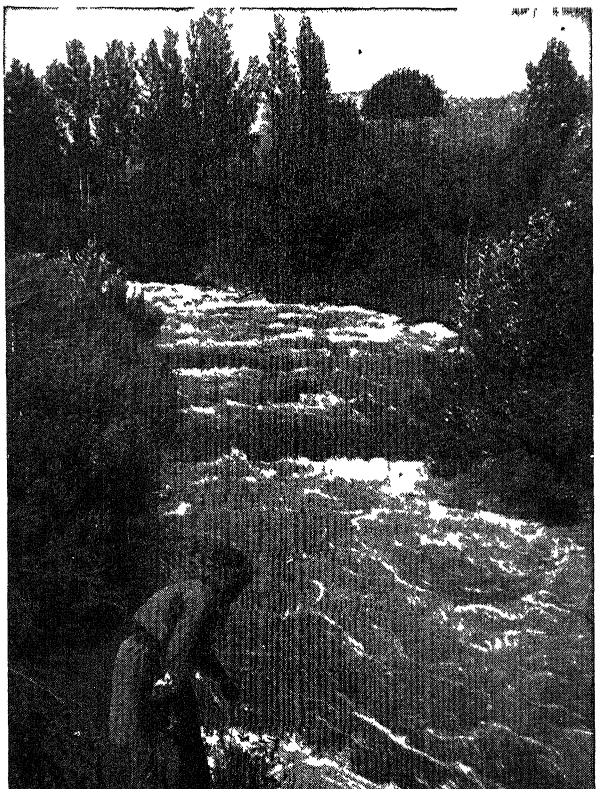
THE ALLALINHORN, SWITZERLAND, WITH AVALANCHE DÉBRIS ON THE FEE GLACIER IN THE FOREGROUND

The location of a divide often has momentous consequences The watershed, for instance, known as the Continental Divide, running through Montana, Wyoming, Colorado and New Mexico, decides whether rain shall flow into the Pacific or into the Atlantic and the Gulf of Mexico. Two streams of water, rising a few feet or inches apart on a plateau in the interior of Brazil, may reach the Atlantic thousands of miles apart A few inches eastwards or westwards, northwards or southwards, make a world of difference Again, the divide between the basins of the Mississippi and the St Lawrence decides destinies as different as the courses of these two rivers; and in this case the divide is so low that in times of flood it is possible to pass by canoe from one river to the other.

We have said that most rivers are originated by rain which trickles and runs into certain channels, but in many instances they originate only indirectly in this way; often their source is a spring. In other cases, they gush out from underground almost fully formed This is the case with a river that flows into Klamath Lake, in the south of Oregon.

The area of country drained by a river is known as its "basin", and this area is, of course, delimited and defined by watersheds. The actual course of a river is known as its "track", and in a typical river it may be divided into three parts — the mountain or torrential track, the valley track and the plain track

The torrential or mountain track has a slope of fifty feet or more in the mile. Down such steep tracks rivers rush headlong, often at a rate exceeding twenty miles an hour The torrent of water pouring over a rough bed works much destruction, uprooting trees, rolling down boulders, eroding away rocky or earthy banks, cutting deep ravines in the mountain-side



© Underwood & Underwood N Y

THE LOWER SOURCE OF THE RIVER JORDAN

This spring at Tell el-Kadi, or Dan, bursts forth into a wide crystal pool, sending forth at once a broad river into the plain

The valley track has a slope of up to ten feet per mile, giving a velocity to the stream of up to five miles an hour A moderate current runs at the rate of one and a quarter miles in the hour In the valley track of its course a river both constructs and destroys; it carries débris from place to place.

Rushing along at eight miles an hour, a stream can displace boulders four feet in diameter; "at two miles an hour stones as large as a hen's egg are rattled along; at one and a third miles an hour the current can just roll pebbles one inch in diameter; when gliding at half a mile an hour, gravel as large as peas is swept forward, while at a quarter of a mile an hour a river cannot disturb fine sand". The carrying power of a running water increases as the sixth power of its velocity so that if the velocity of a river doubles, its transporting power is increased sixty-four times; and if the velocity trebles, its transporting power is increased seven hundred and

twenty-nine times. In certain parts of its valley track a river will dislodge stones and gravel, and at other parts, depending on its velocity, will deposit them.

The plain track is the track of the river across level plains which often are formed of its own deposits. In this track its flow is often split, and hemmed, and dammed.

The courses of the Rhine, the Rhône, the Danube, the Ganges, the Indus, the Mississippi, the Amazon, the Nile and the Niger all can be divided into the above-mentioned tracks. When the slope of a river exceeds ten inches in a mile, or 1 in 6336, it is not navigable without locks. The rate of flow of a river is naturally retarded by irregularities of its bed; and the layers of water next the bottom and the banks, being retarded by friction, move less rapidly than layers of water towards the center. When a river is impeded by any obstruction along one bank, it forms a deposit at that point, and swerves round to the opposite bank, which it tends to scoop out. The scooped-out concavity, in turn, makes the water curve again to the opposite bank, where it repeats the scooping-out process. One curve necessarily leads to another like it, in conformity with the law of the reciprocity of curves. In the middle of its course the Mississippi forms a series of curves so much alike in shape and size that the Indians and earliest colonists used them for the purpose of estimating distances. The larger the stream, the longer the curve it describes. A brook may make several curves in a single small field, whereas a large river may make a curve of ten or twenty miles, and come back almost to the spot from which it started. These curves are called meanders, the name being

American Museum of Natural History

Glacial stream issuing from the Great Illecillewaet Glacier in the Canadian Rockies. The dirt and stones that are shown in the picture have been carried by this famous glacier in its slow progress.

derived from that of the River Maiandros, in Asia Minor, along which many such curves are found

Having made a loop, a river not infrequently takes a short cut again across the loop, and thus are produced diverging and converging arms with an island between Sometimes, having made the short cut, it abandons the loops, which then become a crescentic lake of stagnant water known as an ox-bow lake. In the basins of the Mississippi, the Amazon, the Ganges, the Rhône and the Po there are many of these lakes. Those of the Mississippi are particularly abundant, and are tenanted by alligators, wildfowl and garfish. More than once by such a cut-off the Mississippi has shortened its course by about thirty miles, and has left riverside towns miles from its currents. Thus in 1876 the river cut across a tongue of land opposite the city of Vicksburg, leaving the northern front of the city on Lake Continental, the ox-bow lake thus formed. It was necessary to turn the Yazoo River through a canal across the upper end of the old channel in order to give the city a river front again. By changing its course it has even altered the boundaries of states. A man might go to sleep in his bed in the state of Mississippi, and waken next morning to find himself in Louisiana. Nor is it in America alone that the rivers play such geographical pranks. The Tweed has more than once, by altering its course, transferred farms from Northumberland, England, into Scotland!

A river famous for its vagaries is the Po, which, in some parts of its course, "only takes about thirty years in forming and destroying each of its meanders".

The Hoang-ho or Yellow River, in China, has often changed its course, and sometimes with such disastrous results that it has been named "China's Sorrow". In 1887 this river broke through its embankment, and submerged hundreds of villages, drowning over a million human beings.

The result of the winding or meandering of rivers is greatly to extend their course from source to sea The Scottish Devon meanders for twenty-six miles, to cover a distance which is only six and a half miles as the crow flies. The Forth covers twenty miles flowing between Stirling and Alloa, though the distance direct is only seven miles The Nile, by means of its meanderings, extends its journey by five hundred miles; and the Mississippi, between the mouth of the Ohio and the Gulf of Mexico, goes more than twice the distance, measured as the crow flies. These meanders reduce the gradients of rivers and render them more navigable, and they also increase the efficiency of rivers as means of drainage and irrigation.

Many rivers, as is well known, undergo great alterations in the volume of their water. For example, the Susquehanna

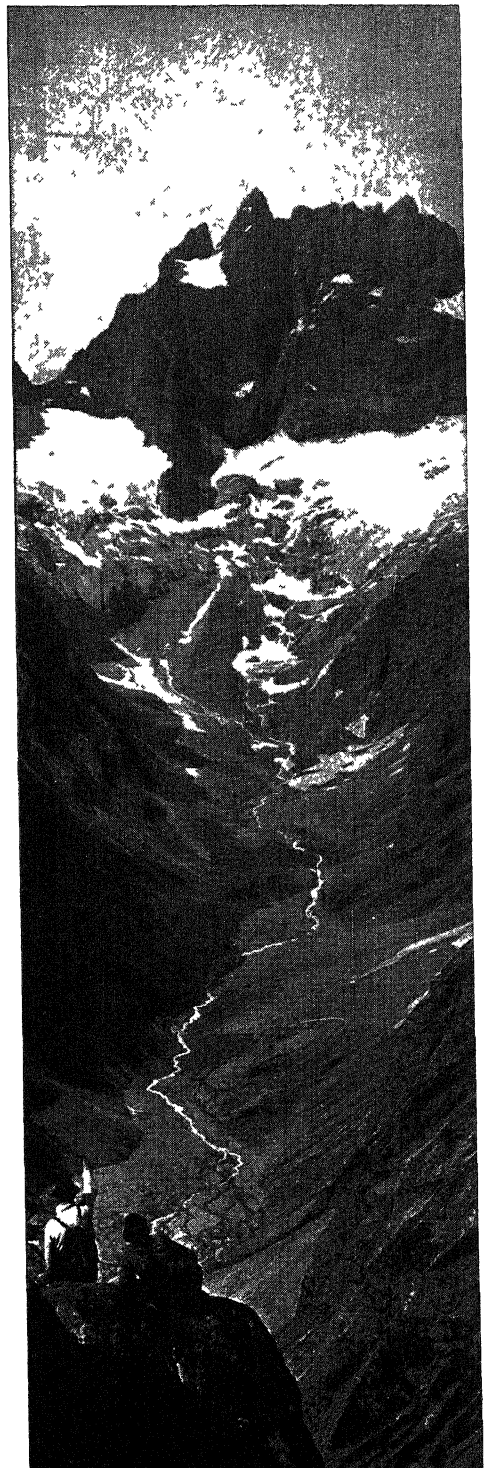
© Ewing Galloway

THE MEANDERINGS OF THE RACQUETTE RIVER AS IT APPROACHES THE LAKE

River at Harrisburg has a mean discharge of about 39,000 cubic feet per second, as indicated by daily observations during a period of fourteen years, 1891 to 1904; but during this period the discharge was at times as low as 2400 cubic feet per second, and once reached a maximum of 544,000 cubic feet; a discharge of 200,000 cubic feet per second is of fairly frequent occurrence.

Heavy rainfalls and melting snow necessarily augment the volume of any river they reach, but the augmentation is not nearly so great as at first sight one would expect it to be, since by no means all the rainfall or snowfall goes to increase the bulk of a river Much sinks into the soil and never reaches the river; much is evaporated; much is given away by the river to any thirsty land it waters. Thus the river discharge for the upper Mississippi reservoirs is about one-seventh of the total rainfall, while the average run-off of water or the whole Mississippi drainage-valley is about one-fourth of the rainfall, and throughout the United States the rivers carry off less than one-third of the precipitation, two-thirds being removed by evaporation. The Thames discharges less than a third, the Elbe about a quarter and the Seine not more than a third of the rainfall of their respective basins.

But though the volume of rivers is not always augmented in proportion to the rainfall and snowfall of their basins, yet the volumes of all rivers fluctuate to some degree according to their supply of water. Often these fluctuations are very sudden and very great. A mountain stream which may be only a runlet will, on the occasion of the first thaw, be suddenly changed into a river running thirty miles an hour, and big enough to overspread fields and wash away houses There are, for instance, three little streams in France, the Doux, the Erieux, the Ardèche, which usually discharge 20 to 25 cubic yards of water a second, but during a flood in 1857 they discharged at the rate of 18,000 cubic yards a second — as much as the discharge under ordinary circumstances of the Euphrates and the Ganges. On this occasion the Ardèche rose to a height of 60 feet above

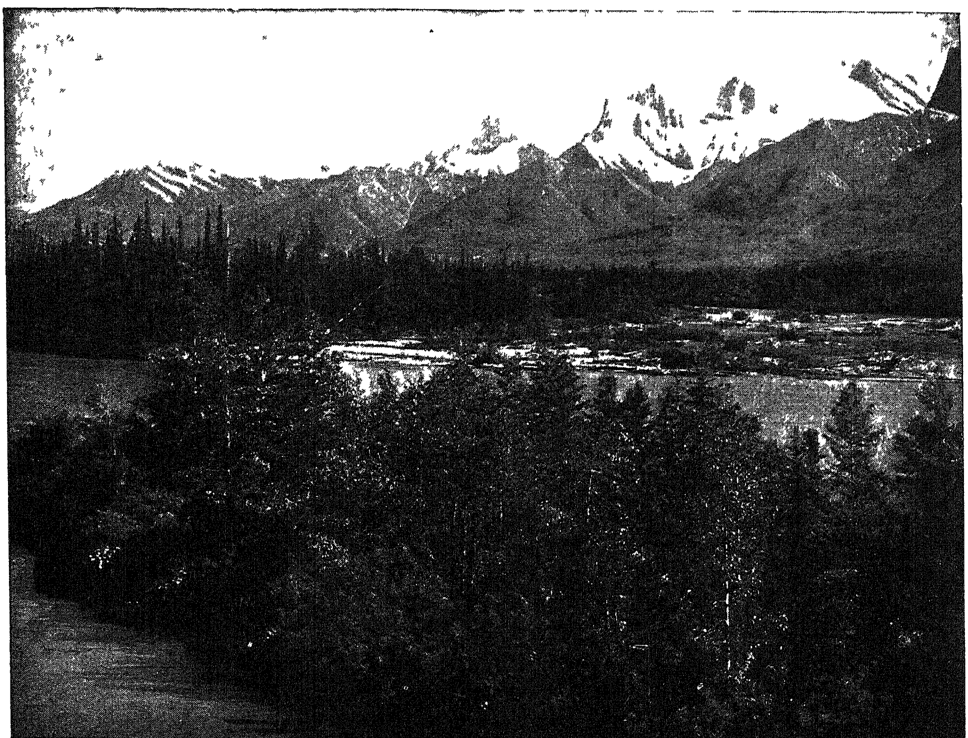


A RIVER ISSUING FROM THE MELTING SNOW IN AN ALPINE VALLEY

low-water mark The Rhine is frequently flooded, and sometimes rises 23 feet, and discharges about 20,000 cubic yards of water a second. If all its mountain tributaries were in flood at once it would become a second Amazon, and would discharge more than 130,000 cubic yards of water a second The Seine has been known to rise 20 feet, the Saône $24\frac{1}{2}$ feet and the Danube 60 feet above low-water level; the difference of level of the Susquehanna in the two extreme cases mentioned above was 25 feet 8 inches

river, and is lulled to sleep by the noise of the cataracts roaring over the rocks, but when he wakens at dawn next day all he sees is a slender rivulet of water, only visible here and there among the masses of gravel "

The fluctuations in volume of the Amazon are peculiar This great river receives tributaries both from the northern and the southern hemisphere. The northern tributaries are in flood in summer and autumn, and the southern tributaries in winter, and so the level of the water



A RIVER VALLEY BELOW THE MOUNTAINS — THE BOW RIVER, ALBERTA

In tropical regions the rivers of medium size are usually dry half the year and in flood half the year. All round the Red Sea there is a perfect system of river-beds, but except during the season of the rains there is no water. One of these dried-up rivers, the Roumah, is 750 miles in length.

In some tropical valleys there are daily fluctuations owing to daily storms. "In the evening all the gorges are filled with masses of raging water; and the traveler finds himself compelled to put a stop to his journey. He bivouacs on the edge of the

in the mighty stream is kept high and pretty constantly in flood. The overflowing of the Amazon is a deluge rather than an overflow, for in places it makes a lake large enough to cover the whole state of New York.

"The great river was terrible to look upon," writes Herndon, the American traveler, "as it rolled through the solitudes with a solemn and majestic air Its waters seemed to wear a wrathful, malevolent, and pitiless aspect. The entire landscape had the effect of stirring up in

the mind a feeling of horror and dread similar to that produced by the imposing solemnities of a funeral at sea, by the minute-gun firing at intervals, the howling of the tempest and the wild uproar of the waves, when the crew assemble on the deck to bury their dead in the bosom of a troubled sea."

In former days the Mississippi was subject to floods resulting in great overflows, but much has been done in recent time to confine the river between artificial embankments known as levees The Ganges, too, has its flood, and every April converts the plain through which it flows into a lake 32 feet deep.

The most celebrated floods in the world are probably the periodic floods of the Nile, which irrigate and fertilize the land of Egypt. All of a sudden in dry, sunny weather the Nile rises, and continues to rise till at its highest its volume is increased ten or twenty fold. To the ancients the rise was a prodigy and a marvel, but we now know that the rise is due to rains and thawing snows on the Abyssinian mountains of the upper reaches of the Nile.

As is well known, rivers vary in color, and sometimes by their color they have been named. Thus, the Greeks have a river Aspropotamo, or White River, and there are many Rio Blancos, while a certain stretch of the Nile is known as the White Nile There is also in the United States the Red River, and in China the Hoang-ho or Yellow River; while in Scotland there is the Blackadder, and in Masailand the Black River. It may be noted here, however, that the word "Orange" in "Orange River" refers to the House of Orange and not to the color of the river, and that the Niger is not so called because black, but because "N-eg-hirren" is the native word for "river".

In some cases the color of a river is due to the color of its bed or of its reflected banks Thus, the Black River of Masailand appears black because of the black lava over which it flows In other cases it is the contents of the river, such as clay or peat, that give the river its characteristic color. Thus, the Blackadder is blackened by its peaty contents; and there is an inky-black stream in Algeria whose waters are really black owing to the fact that one of its two tributaries absorbs iron from the soil, while the other absorbs gallic acid, the mixture of the two accordingly producing actual ink. Rivers vary also in taste according to the mineral ingredients they contain. Some are actually salt, like the Salt River of Australia, and some are acid, like the Rio de Vinagre, in Central America.

THE DEVASTATING FLOODS IN THE VALLEY OF THE MISSISSIPPI

When we look in a general way at the distribution of rivers one of the first things that strikes us is the fact that the distribution is decidedly unequal, and that the Atlantic Ocean receives more than its fair share of river water.

How the Atlantic Ocean receives more than its share of river water

Into the Atlantic flow almost all the great rivers of the world — the Amazon, Mississippi, Orinoco, St. Lawrence, Paraguay, Paraná, Congo, Niger, Gambia, Danube and Nile. Into the Pacific flow only five big rivers — the Hoang-ho, Mekhong, Yangtse-kiang, Amur and Columbia.

Looking at the continental distribution of rivers, we find that Asia has three great rivers running northward across the great plain of Siberia, and four pairs of great rivers running southward. The three great Siberian rivers are the Ob, the Lena and the Yenisei The four pairs of great southward rivers are the Tigris and Euphrates, flowing into the Persian Gulf; the Ganges and Brahmaputra, into the Bay of Bengal; the Indus and Sutlej, into the Arabian Sea; and the Hoang-ho and Yangtse-kiang, into the Pacific.

The great river systems of Europe, Asia, Africa and Australia

Europe has two great river systems — one that includes the Volga, Dwina, Niemen, Bug and Dnieper, which rise in marshy ground in the center of Russia, and one embracing the Rhine, Rhône, Danube and Ticino, which take their rise in the heart of the highest mountains. It is noticeable that the four last-mentioned each reach a different sea: the Rhine the North Sea; the Rhône, the Mediterranean; the Danube, the Black Sea; the Ticino, the Adriatic.

Africa has several great rivers — the Nile, Niger, Congo, Zambesi, Orange and Limpopo. All these arise in the center of the continent, but at great distances from each other and all run comparatively straight courses and have few tributaries The Nile flows into the Mediterranean, the Niger and Congo into the Atlantic, and the Zambesi, Limpopo and Orange into the Indian Ocean.

In Australia the only considerable rivers are the Murray, and its tributary, the Darling. Most of the others are in flood in the rainy season, and almost entirely dry in the dry season.

The western hemisphere's gigantic river systems

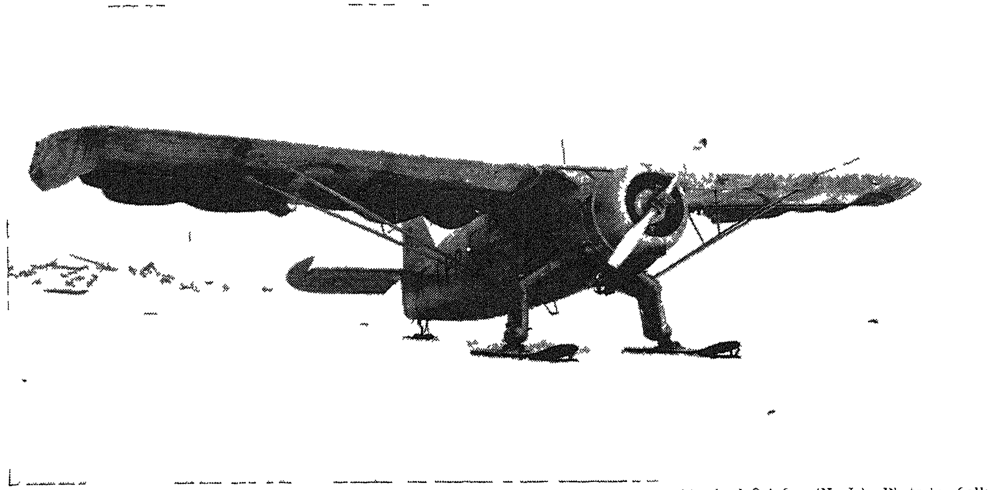
In North America there are two river systems arising from mountain ranges, and a third intermediate river system rising from an elevated plain From the Union Peak range, in Idaho, radiate the Missouri, Colorado and Rio Grande del Norte Further north, from the Murchison range, rise the Fraser, Columbia, Saskatchewan the Athabasca and the Mackenzie, while between these two groups, from a plain situated to the west of Lake Superior, spring the Red River of the North, the Mississippi and the St Lawrence

Of all the continents South America displays the greatest rivers, for it owns the Amazon, the Paraná and the Orinoco, while some of the tributaries of the Amazon and Paraná are themselves huge rivers. The Amazon and the Orinoco rise in the Andes, the Paraná from a high plateau in the interior of Brazil; and all three communicate by tributaries, so that there is a continuous network of water from the north of the continent almost to the south The Paraná joins the Paraguay to form the estuary known as the Rio de la Plata

It is a remarkable fact that the basin of the Amazon is the gentlest landslope in the world; even at a distance of 1900 miles from the sea it attains an elevation of only 600 feet. Its average gradient, therefore, for that distance is less than four inches in the mile, a decline so slight as to emphasize greatly the dimensions of the river, for, notwithstanding this leisurely flow, the volume of water discharged is enormously larger than that of any other.

The following table, collated by H. R. Mill, draws some interesting comparisons.

River	Area of Basin Square Miles	Rainfall of Basin Cubic Miles	Average Annual Discharge Cubic Miles	Length in Miles
Amazon .	2,230,000	2834	528	3060
Congo . .	1,540,000	1213	419	2900
Nile . . .	1,290,000	892	24	4000
Mississippi .	1,285,000	673	126	4200
La Plata .	995,000	905	189	2000



Standard Oil Co (N J) Photo by Collier

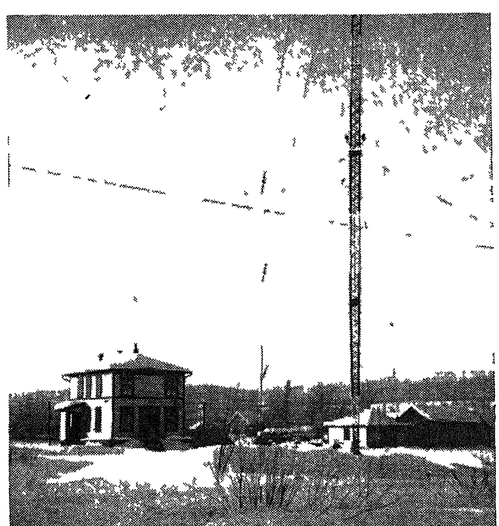
As soon as snow is on the ground and rivers and lakes are frozen solid, planes convert from wheels to skis. Thus equipped, they can utilize any frozen body of water or smooth expanse of snow as an airport

ARCTIC AND ANTARCTIC PROGRESS

There was a time when the Arctic and Antarctic were forbidding fastnesses of ice and snow, which men penetrated only at rare intervals, with great fatigue and at great peril. We have already made much progress in our conquest of these regions With airplanes and cameras explorers have charted immense regions. Scientists have studied geological formations as well as plant and animal life. Both the Arctic and the Antarctic are rich in the promise of mineral wealth. The Arctic is of outstanding strategic importance, too, as a possible avenue of attack in a future war.

U. S Navy

At Little America IV, a famous American base in the Antarctic. The base commander is working over a chart in the air-operations Quonset hut.



Canadian Army photo

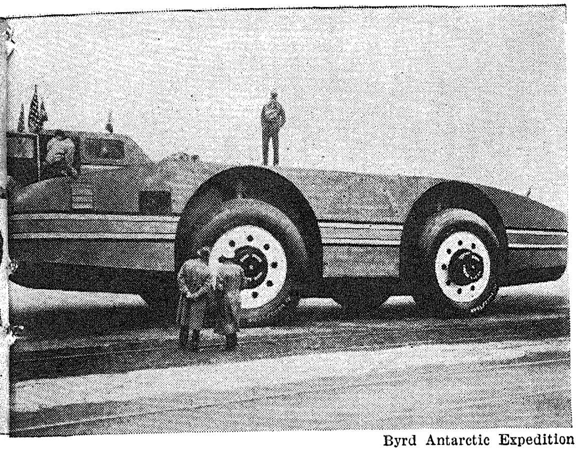
This wireless station at Mayo, Yukon, is operated by the Royal Canadian Signal Corps It provides constant communication with the world at large.

Royal Canadian Navy

Canadian magnetic station at Cornwallis Island, Northwest Territories. This station is used to check observations of the North Magnetic Pole.

U. S. Navy

Sleds are still useful in the Antarctic. The members of a plane crew are hauling equipment to the plane before taking off on an exploratory flight.



Byrd Antarctic Expedition

A Diesel-electric motor snow cruiser used in Antarctic exploration by Rear Admiral R. E. Byrd. It can cross crevasses that would stop a dog sled.

National Film Board

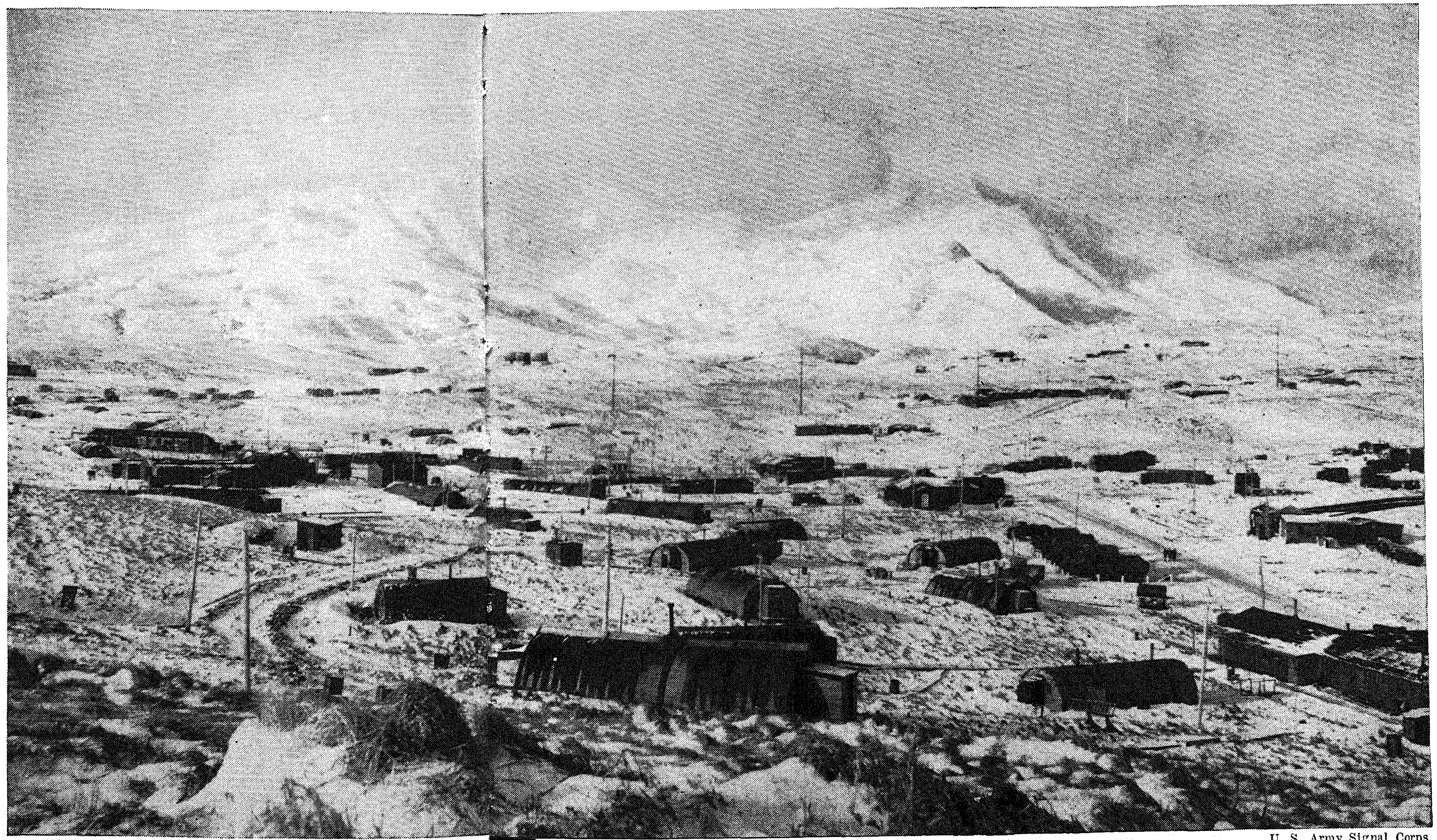
Arctic weather station in northern Canada. When the balloon is released, an electronic device fastened to it sends weather data to ground observers.

U. S. Army Signal Corps

Heavy vehicles use these "ice bridges" of logs.

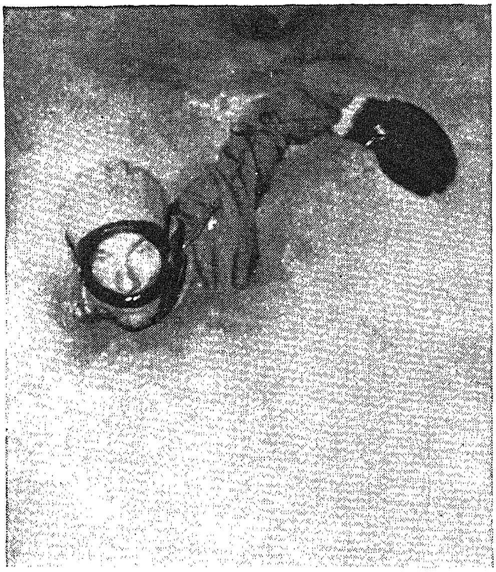
Canadian Army photo

These members of the Royal Canadian Air Force are learning how to erect igloos, or snow huts, as a protection against the icy blasts of the Arctic.



U. S. Army Signal Corps

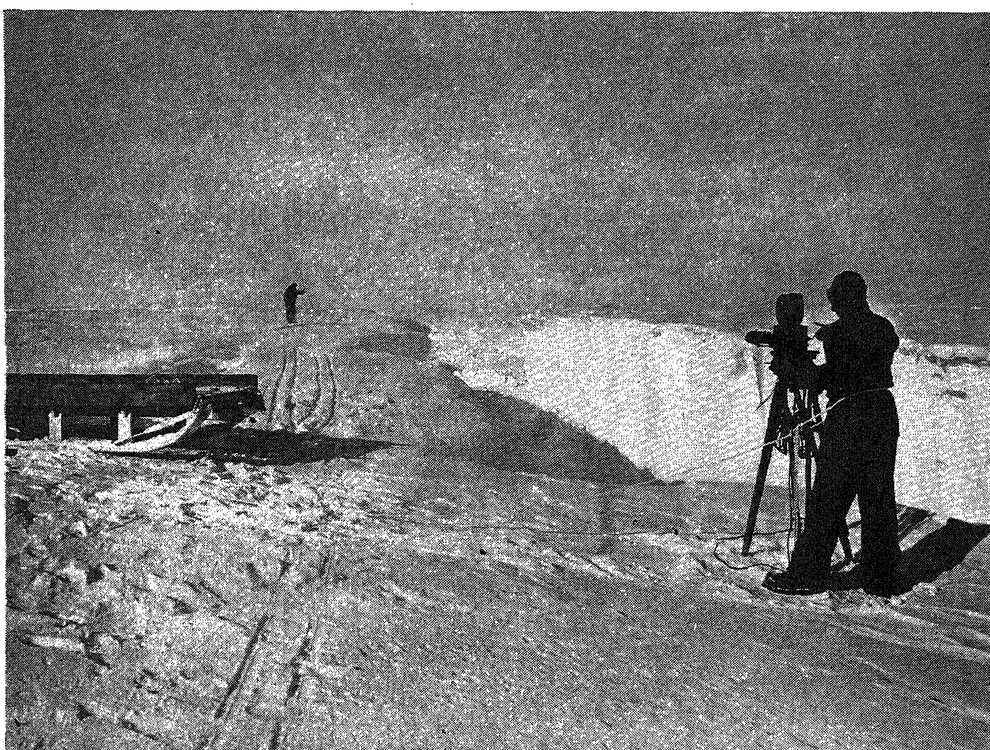
A sprawling base camp set up by United States Army men on Adak Island, off the Alaskan coast. The island is made up largely of tundra, a bleak and treeless kind of plain often found in the polar regions of both hemispheres. The area shown in this picture is covered with mud and snow and is impassable for heavy vehicles. The sudden winds known as williwaws rage on Adak Island, and they make flying hazardous in the extreme.



A one-piece cold-weather swim suit, developed by the United States Navy, is tested in the icy waters of the Antarctic. Under the rubber swim suit this man wears only a suit of long underwear.

Both photos, U. S. Navy

Scientific research in the frozen Antarctic. A member of the United States Geological Survey is at work at Little America IV. He is preparing ice specimens for inspection under the microscope.



U. S. Navy

A Navy cameraman taking a moving picture of a huge crevasse near Little America IV. Navy photographers have brought back a fine pictorial record of life and landscapes in the Antarctic. As a result, much of its mystery has been stripped from that big continent, once a blank space on the map.

RECENT DEVELOPMENTS IN THE OLDEST OF THE SCIENCES

The Story of Important Discoveries in THE INTERESTING FIELD OF BOTANY

BOTANY, THE OLDEST of the sciences, ante-dating even astronomy (which, indeed, grew out of the supposed influence of the stars in the climatic changes of the seasons), must be regarded as the basis of all civilization. It is suspected of having been more or less of an accident, through the return of some wandering tribe to a previous place of temporary settlement to find there growing a crop from seeds left behind; and in this experience to adopt the practice of ripening and storing seeds, to sow again with definite crop-raising purposes. And with this would come the idea of seed selection and crop improvement along botanic lines. Where these first agricultural pursuits began is not known. Every important food plant that the human race depends upon has come down to us from prehistoric times, and in such a degree of development as to demonstrate specific study along botanic lines. However, even with this record of uncounted years of experience, Botany as a science does not hesitate to declare that it is no more today than at the gateway of possible accomplishment in its allotted field. To this day, the living plant is the only agency known to chemistry, by which the waste carbon dioxide of the air can be united with the hydrogen and oxygen of the water of the soil to form the starch which feeds the entire world of animal life—excepting only those which live on other animals whose bodies were built of plant-formed starch.

Much the largest demonstration in the realm of botany during 1936 was that of the nearly 4,000 scouts scouring the country within 50 miles of New York City, under a special WPA fund of $1,125,000, in a search for a further extension of the Dutch Elm Disease than had been recorded for the preceding year. The U. S. Department of Agriculture had warned that this disease may persist as a source of infection in trees long dead, to be found outside the areas already examined. In addition to this phase of the search, other regions fell under suspicion. These included a wide stretch of territory lying to the eastward of New York, and the States of Maryland, Virginia, West Virginia, Tennessee, Missouri, Georgia, Alabama, Louisiana and Mississippi. These localities are being watched, as the elm logs in which the disease was first brought to this country came through seaports in the States named, or the logs traveled through them, or they were made into veneer in mills in those States. The infestation came into this country not from the Netherlands, but from special burls for cutting furniture veneers, exported through France. These were admitted without question, and sent about the country in all directions to furniture factories.

No American variety of elm is immune from attack by the disease; and the effort now being made is specifically to save the magnificent elms so plentiful throughout New England.

Elms in the eastern part of the country are now menaced by another fungus, apparently a native of America. It was first noticed near Dayton, Ohio, several

years ago. It was then attacking both the natural trees in the woods and those which had been transplanted as street trees in the towns. Experiments have been made with a fungus named *Cephalosporium,* on suspicion, and this by transfer tests was found to produce symptoms of the elm disease. At present no remedy is known, and recourse is had to the cutting and burning of infected trees.

Drought-proof corn

The U. S. Department of Agriculture, through its Bureau of Plant Industry, is seeking some variety of corn better able to withstand drought than any standard varieties now grown on the farms of the country. Confidence is placed in the procedure known as inbreeding. In this method, the lines of the parent plants are selected for the qualities desired—abundance of yield; strength of stalk; earliness of ripening, etc. The separate strains are then inbred for generation after generation until they are about to dwindle to runts—just about to perish from the poison of their own germ plasm. Then they are interplanted with another line possessing desired qualities, and similarly inbred. These two lines are then cross-pollinated, and controlled in setting seed grains. The resultant seeds produce races of plants wholly different from their parents, often notable for extraordinary vigor, expressed in great height of stalk, with greener, broader leaves, and laden with heavier ears and more of them. Some of this inbred corn, the result of continued processing for many generations, was found to come through the droughts of 1934 and 1936 in notably better condition than the varieties generally grown on farms, and a new line of hybrids from among these drought-resisting inbreds is being produced to afford, if possible, a practically drought-proof crop.

Tree rings in climate study

In a recent investigation by students of Dartmouth College as to what dependence could be placed on the width of the rings in a tree trunk, as an index of the rainfall over a period of years, in spite of some denials that it was practicable, a formula was achieved. The tree used in the research was the oak, and the period over which the observations were made encompassed 30 years. The factors used in the ultimate formula involved the temperature and the precipitation; so that "the sums of the observed and of the calculated values of these factors, covering the 30-year period, differed by less than 5 per cent." The rainfall at the time of the growing season (previously used in the calculations), proved to be of determining value only when a drought immediately preceded, or a period of heavy rains had occurred; and these conditions, even in locations not far removed, made it impracticable to construct a comparison including both. The rainfall of the April-August period proved to give the best correlation with the period of growth. In cases of previous drought, allowances had to be made for lag by extension of the period into September. Further research showed that the hemlock tree, in its ring formation, carried a truer record of the natural happenings—as to years of drought and those of abundant rainfall.

Miscellaneous paragraphs

The discovery of enormous quantities of fossil bones of more than 30 species of elephants in the Great Plains of Nebraska, now dry and wholly without trees, point to the conclusion that at one time these plains were covered with forests, as grasslands would be unable to provide the green fodder required by such animals—about one ton a day for each—so that they necessarily sought the forest for subsistence. It is argued that this condition in that part of the continent must have preceded the Great Ice Age by a long period.

The Big Trees of California, so long rated as the oldest living things upon the Earth, are rivalled by a juniper found near Hillsborough, in that State, growing at an altitude of about 8,500 feet in the high Sierras of Tuolumne

County. This tree is only about 80 feet tall, due, it is thought, to the fierce winds which sweep that region. At the surface, the trunk has a diameter of 21 feet six inches, but above a level of five feet its average diameter is 14 feet two inches. By the use of a core-cutting auger, this tree was determined to be 3,000 years old (compared with 3,250 years as the greatest age found for any of the Big Trees). During the last 700 years, the auger showed, the juniper had added only two feet to its diameter.

The discovery that two heretofore unknown species of *Tingia* (a genus of cycad-like plants that flourished during the Mesozoic era, many millions of years ago, and now found only in China) at one time grew in Texas, has been made by geologists in that State through the uncovering of their fossils, which appear in the rocks of the Lower Permian Age. Other fossils belonging to the same Age, and associated with the Tingias in China, are also found in the same strata in Texas; tending to prove that at one time there was free migration between Western America and Eastern Asia. It is held by the geologists that this transfer across the area now occupied by the Pacific took place about 200,000,000 years ago.

A form of bacteria occupying destructively the valued nodules on the roots of legumes (the pea family) have been given the name *bacteriophages*. By these nodules the members of the pea family accumulate nitrogen not only for their own use but in large excess, thus benefiting the soil in which these plants grow, restoring lost fertility in many cases. Though discovered some years ago, it is but recently that specimens of these bacteria could be secured for investigation, and now, only from the vetches. It has not been decided whether they are living organisms, or chemical compounds. The harm they do is to dissolve these nitrogen-collecting nodules, and this they are able to do even when diluted with one billion parts of water.

At Dr. Shull's experimental garden of Lamarck's Evening Primrose, at Princeton, only two new strains have been developed among the 40,000 plants there growing: (1) a plant named *acuminata*, because of its pointed leaves; (2) the other called *pollicata*, as it has a solid stem between the ovary and the style. Both of these are regarded as hybrids, and not as variations after the Darwinian hypothesis. As this garden of the *Œnothera Lamarckiana* has been in existence since 1905, its testimony is altogether against the famous hypothesis.

Green and blue molds, which have proved so destructive to oranges, lemons, and other citrus fruits are overcome to some degree by exposing the fruit for a short period to nitrogen trichloride gas. As practically applied, this gas is introduced into storage rooms or refrigerator cars, in which it is circulated by electric fans. The efficiency of this remedy is estimated at nearly 70 per cent of salvage.

In a search for wild varieties of the tobacco plant, to be used for crossing with those now in cultivation, an expedition from the University of California has been searching regions of the Andes. They report the finding of native tobacco plants reaching a height of 60 feet.

In 1940, Arnold reported, among the fossil plants of the middle Devonian period, a new genus which represents the oldest structurally-preserved vascular plants described from North America. Darrah studied some 3,500 fossil plants found in Carboniferous coal balls in Iowa. Over sixty nominal species of fossil ferns and their relatives were studied. Petrified forests were also reported.

Investigation into the "enriching" of land lying fallow has shown that this phenomenon is due chiefly to the decay of roots of previous crops, restoring to an important degree the simple "raw" materials on which all plants depend for growth. Not the least of these is the oxygen absorbed by the material decayed. It was observed that where the roots went deeply into the ground, the

soil was deep; where but a little way, the soil was thin.

The autumn display of color in the foliage being discarded by trees and shrubs at the close of a season's growth is not Nature's parting salute to the taste and art of the landscape painter. To the contrary, it is a strictly botanical bit of engineering, due to the breaking up of the chlorophyll in the leaves in the process of withdrawing it into the tree, to save it for another season. This being done, the tree seals the old stem of the leaf with a double layer of cork cells, and the leaf is freed to drop when it will.

Experiments as to the effect of "heavy water" upon the growth of plants showed that in the case of those with green foliage, while the germination of their seeds was retarded, once they were growing, their development was speeded up, as compared with the effect of normal water. With plants like the fungi, with no green in their structure, the effect of heavy water was disastrous.

The famed Cedars of Lebanon, bought by Solomon from King Hiram of Tyre, have almost entirely disappeared. There remain only five small clusters of these trees, to be found only at the altitude of 6,000 feet in the mountains, above the historic place of their original planting.

Chemistry has come to the aid of the onion-farmer by disclosing that a thick, golden brown skin for his crop, adding materially to its market value, may be assured by the use of a soil dressing of sulphate of copper.

Scars found among the tree rings of California's Big Trees, show that they were reached by fire in the years 1797, 1580, 1441 and 245 A. D.

The successful crossing of wheat with the perennial grass *Agropyron,* with the result of securing a perennial wheat plant, has been announced by Canadian agriculturists, who have been experimenting along this line for some years. The new "wheat" produces a seed closely resembling the wheat grain, on a plant which continues to grow year after year, like its grass progenitor. It will be particularly valuable where the soil is liable to be blown away by high winds in conditions of drought, as it may be drilled in to a depth impossible with grass seed, which must be sown on the surface, and makes from the start a deep root system able to hold the soil in place, and draw upon a deep water supply which grass cannot reach.

The influence of environment

The influence of varied environments upon the characters of a number of species was described in 1940 by Clausen, Keck, and Heisey. Genetically similar members of species collected in the wild were first established in a nursery and then transplanted to different altitudes ranging from near sea level to the summit of the Sierra Nevada Mountains. Observations on the appearance and behavior of the different sets of plants were made at various intervals up to sixteen years. In contrast to the reports of earlier investigators in Europe, every plant retained its individuality regardless of the station or conditions to which it had been transplanted. It was found that different species and races are subject to a certain amount of modification which is temporary, reversible, and quickly induced. Modifications often parallel differences that are hereditary, and it is impossible to distinguish between hereditary differences and modifications, except by experiment. Some plants from the mild climate of the California coast were able to survive the more severe winters at higher altitudes, while others failed; all such plants eventually died at the high altitude alpine station. In general, alpine plants did best at the station whose climate was most like that of their native environments.

HOW PLANTS ARE SPREAD

The Arrangements Whereby Stationary Crowths Prevent Overcrowding by Despatching Their Seeds to a Distance

UNCONSCIOUS SERVANTS OF PLANTS

WE now come to the consideration of one of the most interesting aspects of the life of plants—namely, that of their distribution in the world, or, as it is termed, plant geography. The specialization of function for various definite purposes is nowhere better exemplified than in plants, and we have already studied some of the physiological processes which are carried out by means of special devices. The dispersal of plants over the surface of the earth is another of these definite objects which plant life has to manage in order to survive; and it is almost more necessary to plants than to animals that special means of attaining this end should be developed, for the simple reason that the majority of plants have a definite fixed position in which they grow. All of the higher animals are provided with organs of locomotion; and in their case specialization of these organs, when it occurs, is directed frequently to increasing the speed of their movement, as we find in the wings of birds, and in the limbs of an animal such as the deer.

But although we usually regard plants as living creatures in a fixed habitat, a moment's thought will show us that unless the plant is provided with some means which will permit of its *offspring*, at least, being transported to some distance, it could not possibly survive as a species; or, at least, it could never increase very much in number. It would be in the same position as a human community—restricted either by geographical or other limitations within a given area, beyond which, no matter how great the increase in the population, the individuals could not go.

The inevitable result would then be that, as soon as the individuals reached the number which was the greatest that could be carried by the area in which they lived, every single individual above that number would either be starved for lack of food or would otherwise perish in the struggle for existence. This actual process occurs in nations, which therefore require, as an urgent necessity, colonies or dependencies for their surplus population.

So it is with plants. A very few generations in plant life would bring about such a congestion and crowding in the immediate vicinity of the parent plants that no more could survive unless nature provided some means of dispersal for the younger generations. The necessity is so urgent that we no longer wonder, once we have recognized it, that the variety of means which have been evolved in plants to attain this end is almost infinite. To some of the more striking of these adaptative arrangements we may now turn our attention.

Among the cryptogams, those lowly plants whose organs of fructification are concealed, or not visible, a very common means of propagation is by means of spreading roots, which travel along underground considerable distances, and so extend their area of living. This is seen in the ferns. But most of these flowerless plants reproduce themselves by some sporing arrangement in which the actual spore itself is so minute an object that it is carried with the greatest of ease by even very slight movements in the air, and, of course, with still greater ease by moving water.

The distance to which such minute spores may be transported from their original home can hardly be estimated Doubtless there is nothing to prevent the contents of the ripe puff-ball — full of fine, powdery spores — from traveling over a whole continent in the air, or even traversing a mighty ocean in a storm of wind, while as for the spores of the marine plants themselves their limit of distribution is only to be gauged by that of the ocean currents themselves All that is necessary is that the living principle in the spore be protected sufficiently in order to survive the long, hazardous journey

CREEPING ROOT OF POLYPODIUM VULGARE

We have seen in an earlier chapter that certain plants propagate themselves, amongst other means, by runners or rootstalks, and this is another way in which the plant may gradually come to spread over quite a considerable area. Then, in a somewhat analogous way, we have the spreading of the roots under ground, and the sending up of shoots at intervals, as is seen in the case of trees like the silver-leaf poplar, which may do great damage on lawns by the number of shoots that spring up from underground roots coming from a distant tree In a state of wild nature such trees as this silver-leaf poplar depend upon this method of securing a wide enough area to maintain the species

THE UNDERGROUND ROOT-SPREAD OF GRASS ON A SAND DUNE

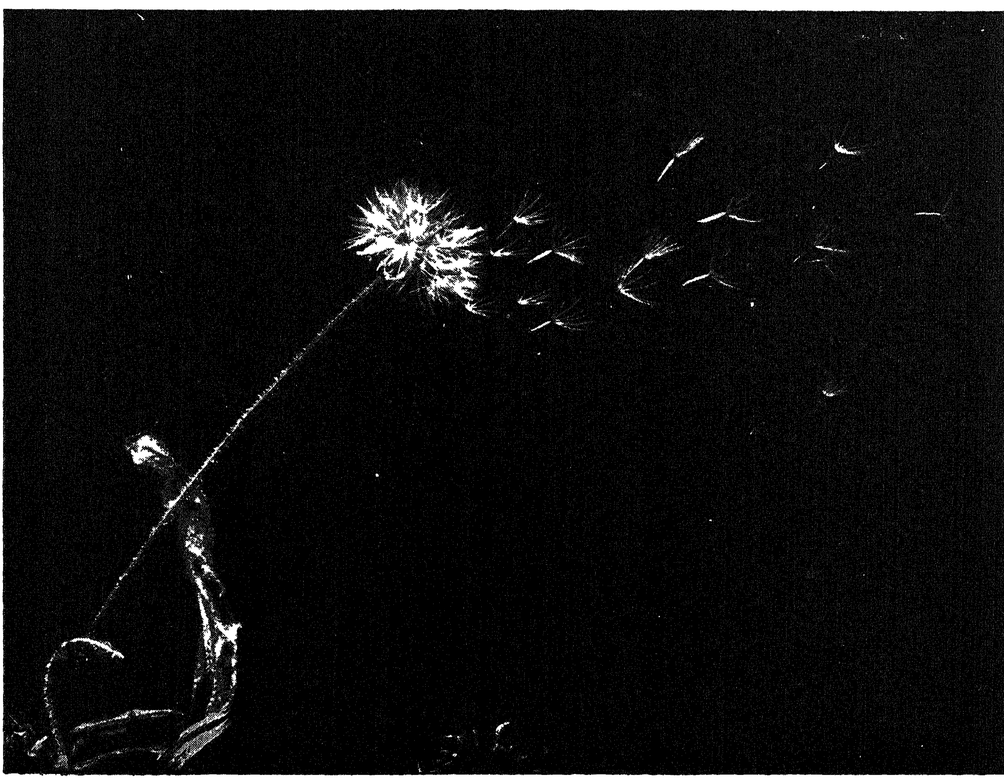
This also occurs in beeches, oaks and a number of other trees The herbs show this habit also, as many who have fought quack-grass will realize

A more unusual and very striking method of gaining the same end is for the branches of a tree itself to grow towards the earth, and on reaching it to strike root This is, of course, only an exaggeration of the process of the runner, as seen in the strawberry But it looks the more odd to see a large branch hanging freely from a considerable elevation, and then striking root But branches may aid in distribution by dropping off the tree altogether, and being carried either by wind or water to some considerable distance, where, again, roots quickly appear from the broken end of the branch Some of the willows and poplars exemplify this process extremely well Among the herbs the walking fern offers probably the most interesting example of this phenomenon

Then we have the large subject of the dispersal of seeds themselves by different mechanisms on the part of the plant, some of which we shall have to study almost immediately But far more commonly than by a special mechanism are seeds spread by external agencies, particularly wind, water and animals, and artificial means of communication between places and countries wide apart

WIND-BORNE SEEDS OF THE DANDELION

FLOATING SEEDS OF THE CARBINE THISTLE



WIND-DISTRIBUTION OF THE SEEDS OF THE HAWKWEED

Occasionally the transport is materially aided by the living principle being inclosed within a hard fruit structure. Sometimes, however, it is the seed itself which is so modified as to help its own progress But all these arrangements, no matter how diversified they may be, have the same object — namely, to avoid overcrowding of individuals in one district

Another very curious arrangement for this purpose is seen in such fruits as, when ripe and dry, burst open with a considerable degree of force, and throw the seeds some distance, as is the case with touch-me-not or jewel-weeds, geraniums, violets, oxalis and witch hazel This process is in some plants attended by quite an audible noise

Then we have fruits and seeds in considerable number that may be termed "winged", because of the remarkable membrane-like wing attached to them, which serves the purpose of sails, and by means of which dispersal is aided. Examples of this particularly interesting, though quite common, type of dispersal are seen in the ash, the elm, the maple and other trees, those of the maple being figured on page 2743 Still others have exquisite little tufts of fine hair which serve as parachutes, as is the case with the sycamore. When set free into the air the seeds are carried by currents of wind to immense distances by the hairs acting much as the sails of a ship

This arrangement is one of the most perfectly successful of the means for dispersal, as may be gathered from the observations of the number of thistles and dandelions that spring up in any district where these plants are allowed to mature Each of them produces tufted or parachute fruits in great numbers, as do many other plants, and consequently their distribution is world-wide Another arrangement is that of certain plants which, when dried up, are easily blown about over the surface of the ground, and drop a few seeds here and there as they go. The more rounded in form such a plant is, and the lighter in structure, the better will it carry out its mission. Russian thistle, tumbling mustard and a species of panic grass illustrate this well

A RIPE BULRUSH AND ITS SHED SEEDS

MOSS SPORES CAST TO THE WINDS
From a highly magnified photograph

An exquisitely ingenious arrangement is seen in the capsule of the common poppy, which is constructed practically on the same principle as a pepper-shaker. Within the capsule in the poppy an immense number of minute seeds are produced, and when the period of maturity arrives these are shed in small quantities at a time through

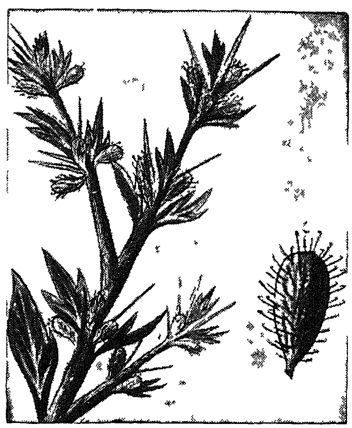
apertures that allow only a certain number of them to emerge at once. Very similar arrangements are to be seen in the monk's-hood and the larkspur

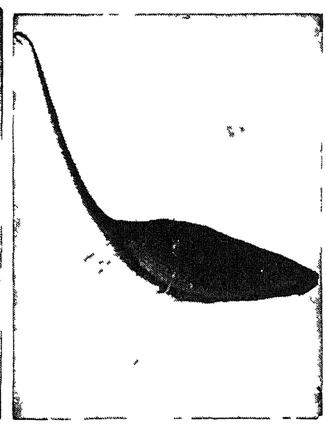
It is difficult to estimate the importance of water in plant distribution, but anyone who will take the trouble to collect a number of the fruits and seeds of plants, and place them in a pan of water, will be surprised to observe how large a proportion will float Still more interesting is it to leave them for a day or two, and notice what proportion will still remain on the surface of the water. In this way it is brought home to one that water-carrying must be a very important means of seed-dispersal. The current of river and stream, the breeze that ruffles the lake or ocean, supply the motive power for these seeds.

One of the best known of these water-travelers is the cocoanut palm. It has been estimated in some cases that the seeds of this palm have found a new home by floating more than a thousand miles uninjured. An examination of the fruit shows how easily this might happen. Quite a large number of species of plants are known to disperse themselves by thus drifting in currents of water. Many of the sedges, docks and other plants growing near our freshwater streams and ponds may use a similar method to disseminate their seeds and fruits. The fruits of sedges are frequently contained in a little sack which floats, and those of dock have floating devices which remain attached to the fruits when they are shed.

Then many plants have evolved arrangements by means of which any passerby, be he man or beast, is compelled, willingly or unwillingly, to assist in their distribution. Everyone is familiar with the burrs which adhere to one's clothes after a walk in the country at a certain time of the year These outgrowths take the form of hooks of some sort or other, and so effective is their strength of attachment that it is hardly possible to get them out of the hair or wool of cattle and sheep without actually cutting the hair with them A very interesting case is quoted by Joseph Young Bergen in this connection. A buffalo, whose hair was full of some fruits of a peculiar kind of grass, was sent as a present to a leading personage on the island of Ternate, in the Malay Archipelago This particular kind of grass, hitherto unknown there, rapidly spread over the whole island as the result of this method of introduction.

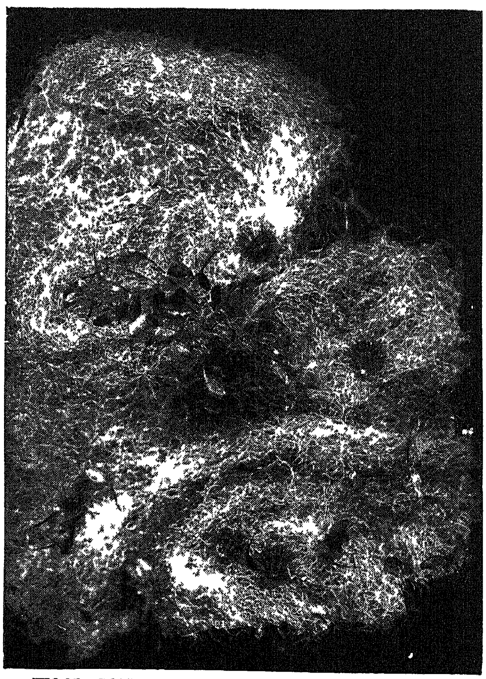

GOOSE-GRASS BURR


THE BATHURST BURR


THE HOOKED AVENS SEED

Then, of course, we have the whole army of stone-fruits and fleshy fruits to consider in this connection, because most of these being eaten, either by man himself or other animals with more or less similar tastes, are naturally very important means of scattering the seed within the fruit, the fleshy part being eaten and the seed discarded or in some cases the seed passing through the alimentary tract of the eater. It is worth noting, in passing, that possibly the deliciousness of these fleshy fruits has been evolved quite definitely for the special purpose of scattering the seeds.

Plants possibly do not evolve structures for the benefit of any living thing but themselves; and if this is so one might imagine that the reason why the pulp of so many fruits is eatable and palatable is to form an attraction to some fruit-feeder, as the result of which, having satisfied his own palate, he will drop the seed at a distance from where he gathered the fruit. Evidently for the same reason the covering of the actual seed itself in many of these fleshy fruits is much too hard to be either changed during mastication or digested if swallowed; and such



WOOL CONTAINING VARIOUS HOOKED SEEDS

seeds, being carried within the bodies of animals, are ultimately scattered abroad with the excrement of the creature. In this category come such fruits as the fig and the currant, whilst in the former we may mention the peach and the date.

In the cases just mentioned, from the sticky burr to the swallowed currant-seed, the part played by the animal was either unconscious or, at any rate, not deliberate. But there are other instances in which animals purposely carry about seeds, probably in order to store them up for future food.

When a thing like this happens it is usually the fleshy part of the whole fruit that is devoured, and the actual seed, which contains the embryo, is left. So ants carry away seeds thus provided with a fleshy covering, and some of these seeds appear to be constructed as if of set purpose for the ant to handle. Similarly, too, our squirrels store up nuts and acorns in different places as a provision for winter food, but quite frequently they forget where they have put them, and thus become unconscious scatterers of the seed itself.

A still further refinement of a similar adaptive plan is seen in succulent fleshy fruits extremely bitter to the taste until such time as the true seed is ripe within. Then they become attractive to the animals that play the part of distributing agents. The orange is a case in point.

From the foregoing preliminary statement as to the chief methods adopted by plants to disperse themselves, it will be realized that foremost among these methods must be placed those which either in one way or another have reference to the disposal of the fruit. We may therefore at this point pay a little attention to the fruit of plants strictly from this point of view, reserving to a future occasion other interesting aspects in the study of fruits

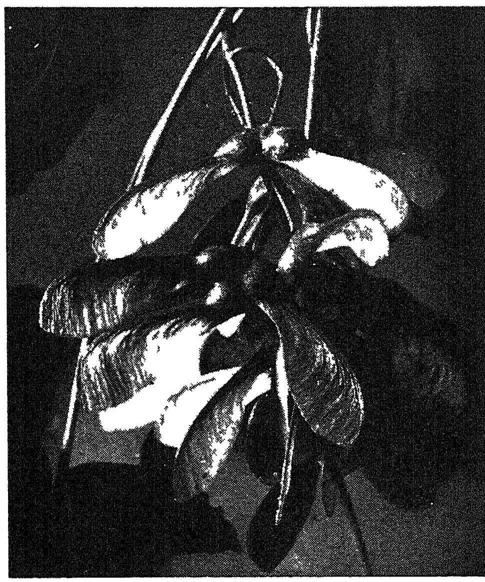
The fruit arises from the flower or flowers of a plant and sometimes the adjacent parts after the process known as fertilization is completely finished. It will be enough if we realize at this stage that a pollen grain grows and enters what is to become the seed. It produces a sperm cell which unites with an egg-cell inside the ovule, as the result of which the ovule itself may ripen and become a seed. Now, the term "fruit" means a great deal more than the mere seed itself.

Botanists state that a fruit is a ripened ovary and the parts which adhere to it. The ovary is the ripened lower part of the pistil of the flower and contains the seed or seeds. In a strawberry fruit, then, the fleshy part which we enjoy is the ripened receptacle which bears over its surface the small, dry ripened pistils each of which contains a seed

In the case of the apple the part which we ordinarily eat is the very much enlarged receptacle which here has grown around the ripened pistil or core which, as you know, contains the seeds. All of these variations naturally lead to variations in the methods of dispersal.

Some of the coverings of the pistil, when they attain full ripeness, open with a spring-like movement, sudden in its onset, having more or less explosive force, as it were, sufficient to scatter the seed to a distance of two or three feet from the plant. More effective and more striking are the special structures frequently found attached to the seed or fruit, which enable it to sail through the air more or less like a parachute. We have already referred incidentally to the clump of fine hairs acting in this way in connection with the fruits of the thistle and the dandelion. The fruits of these plants, by means of the modification mentioned, are enabled to spread themselves over immense areas of ground, and to be carried for enormous distances.

SPORES OF ALGÆ SCATTERED IN THE SEA



THE WINGED FRUITS OF THE MAPLE

This mode of dispersal may be seen in many of the ripe pods of the leguminous plants, such as the peas and beans. In them it may be observed that, after the pods have burst, the valves within them quickly twist themselves up.

But inasmuch as the wind and currents of air are the most potent factors in the dispersal of seed, it is natural to find that the great majority are sufficiently small in size and light in weight to be easily carried for a considerable distance in the wind. There are, however, special adaptations to assist in this process. For one thing, many seeds are quite round in shape, which enables them to be easily moved along a sufficiently smooth surface by any propelling force acting as wind does.

Very remarkable, too, are the structures, looking like wings, which are seen in the case of the fruits in the ash, the elm, the sycamore and similar plants. The seed in these cases is a fairly heavy structure, and if allowed to fall will do so almost vertically, even though its wings cause it to flutter. But if we watch what happens we shall observe that these fruits, or seeds, are more frequently detached from the trees when the wind is of a very considerable velocity or force. Then the wing-like apparatus with which they are furnished assists in their being carried through the air for a long distance.

With regard to the part played by animals, too, we find in many of the umbelliferous plants, such as the carrot,

special structures in the form of spines, or hooks, that cause the fruits to adhere very readily to the covering of any animal they come in contact with. Ultimately, they are rubbed off the animal's coat, often at a considerable distance from their place of origin.

We have already referred to the dispersal by animals of the seeds which lie within the fruits they eat, these seeds passing through the alimentary tract of the body without being injured. This involves some special form of protection against the digestion of the embryo within the animal's stomach. So we find that in these cases there is a very hard, dense pericarp, or fruit-covering. This structure, the pericarp, is sometimes the attractive portion to the animal. For instance, in the group of berries, like the cherry and the plum and so forth, the pericarp itself forms the attraction to the animal.

In what we popularly speak of as the stone-fruits, there is a hard covering within, the endocarp, which quite effectively prevents any digestive process injuring the seeds while in the body of an animal. These firm, hard coverings will persist for a very long period of time, enabling the seed to be preserved until chance, or design, brings it into such an environment as stimulates it into new growth. Then the protective coverings disintegrate, and the embryo, having passed unscathed through winds and waters, and even animal bodies, is enabled to bring forth a new individual, possibly thousands of miles from the spot where the fruit was produced.

Some special examples of modifications which play a part in plant dispersal

An interesting arrangement of the spread of some lowly plants is that seen in connection with the formation of what are spoken of as fairy rings. These occur frequently in meadows and under trees. Some of the fungi produce very picturesque results. The first growth in the region of a ring is made by the fungus. The food consumed by that year's growth cannot, of course, be used the following year, so the fruit bodies appear around the area occupied by the first growth. The following period of growth is still further out and so on until finally a more or less definite ring appears. The original fungus is all the time moving outwards in a larger and larger circle, into the region where the food has not been exhausted and so the ring gets bigger. Country folks used to associate these ring-like patches with the dances of fairies, or elves, or witches, and popular superstition in some countries attributes their origin to dances by the fairy folk on the night of the 1st of May.

Other fairy rings are formed by plants which send forth underground runners, the growth dying in the middle, but extending peripherally. Thus, distribution of plants by offshoots frequently produces an area of distribution of a circular shape, becoming larger and larger. Of course, it is necessary that the original plant should die, that its growing points should radiate outwards, and that the successive plants should also die, leaving only the living ones at the circumference.

Just as some plants distribute themselves in circles, so do others in more or less straight lines; and this latter formation is the result principally of roots that run horizontally under the soil, and give off buds at intervals. The long connecting root may die here and there, leaving these new individual plants growing more or less in a straight line. The raspberry is a plant which conforms somewhat to this arrangement. A group of raspberry plants moves about three or four feet every year; and so it often happens that raspberries planted near a hedge or fence may, in the course of a few years, be growing quite well on the other side of the fence (possibly owned by someone else), while the original plants have entirely died out.

Dispersal by means of underground tubers is sometimes wonderfully fast, and gives rise to quite large colonies, which gradually spread over a larger and larger area. This sort of process is well seen in the artichoke, whose colonies may be regarded as being arranged in clusters.

The rapidity of the spread in such cases as this will depend upon the length of the underground growth, and the nature of the soil.

The extraordinary rapidity of the dispersal of a plant over an area of ground by means of offshoots on runners is well seen in the strawberry, as described by the Austrian botanist Anton Kerner:

"Suppose a strawberry stock sends out three runners during the summer: each takes root at five nodes, and from each node a bud — *i.e.*, an offshoot — develops, so that the following year the mother-stock is surrounded by fifteen daughter-plants. It should be noted that the length of the internodes in each runner is unequal. For example, in one which had extended over the ground in the shade of the wood, the first internode was 37, the second 34, the third 31, the fourth 30 and the fifth and last 22 cm.; thus the offshoots were the closer together the greater their distance from the mother-plant. Next summer fifteen new offshoots were again formed from each of the original fifteen, arranged in exactly the same way; and in the forest glade, where two years previously there had been only a single strawberry plant, occupying a space of 50 sq. cm., there would now be 200 plants distributed over a space of about 3600 sq. cm."

Of course, when plants change their position merely by sending out offshoots in one direction or another, while they themselves die in an opposite direction, the actual range of distribution is naturally restricted. It is, however, very much increased when we have to deal with plants whose offshoots become separated from the parent stalk, and can be transferred by any of the agencies of wind, water or animals to fresh pastures. In this way the range of distribution of a plant may be extended in a very few minutes over an area which would take many years to cover by ordinary runners. On the other hand, it is not so certain a means of survival, because the detached offshoot may land in an unsuitable environment, but, considering the number of shoots provided for such a purpose, the object is usually successfully attained.

Very few plants produce special organs which enable their shoots to move about on their own account, and when these do occur it is only in the lowly plants which inhabit water. Many, however, are carried passively by water, such as the green algæ, those slimy masses we often see on a sluggish pool, or covering the surface of submerged stones. These plants detach portions of themselves freely, and each portion starts a new growth in a new place. No simpler means of distribution could be conceived.

The seaweeds, and similar plants, appear to owe their distribution mainly to the force of circumstances. Portions of them are torn asunder during the high tides and rough weather, and carried hither and thither until they are deposited into spaces between rocks and stones, or in sand, where a large proportion of them may start fresh growth.

THE ONLY BIRD MONUMENT IN THE WORLD

In the summer of 1848 the early settlers in Utah were saved from starvation by great numbers of gulls which flocked to their fields and consumed the swarms of "crickets" which threatened to destroy all their crops. This handsome monument was erected in Salt Lake City to commemorate the incident.

The illustrations in this chapter, except this one and two others, are from photographs by A. A. Allen.

BIRDS AS MAN'S HELPERS

What They Do for Us and How We Can Attract Them about the House and Garden

OUR FEATHERED ALLIES IN AGRICULTURE

IN Salt Lake City stands a granite column surmounted by a great sphere with two gulls of gilded bronze just alighting. The square pedestal bears four historical bronze plaques in high relief, and is surrounded by a fountain forty feet in diameter, in which water lilies grow and where song birds come to drink and bathe. It was erected to commemorate an incident in the summer of 1848 when the early settlers were saved from starvation by great numbers of gulls which flocked to their fields and consumed the swarms of "crickets" which threatened to destroy all their crops. The monument is unique. Still in a larger sense, the whole verdant world with its green trees and rich harvests is a monument to the thousands of insectivorous birds that have unwittingly labored for humanity against the millions of insects.

Every year hundreds of thousands of children are enrolled in bird clubs or bird study classes They constitute a monument of a different sort, expressive of the love and interest that mankind bears toward birds irrespective of their economic value Indeed the bright colors of birds, their cheerful songs, their many interesting ways seem so apart from the turmoil of everyday life that we have come to look upon bird study and bird protection as having little bearing upon the economy of our existence, little influence upon successful agriculture.

Let us, therefore, forget for the moment that there is anything of interest in birds, that their presence in any way affects our health or happiness, and consider them only from a strictly economic point of view as they affect food production

With this in mind we shall recognize five main groups of birds: (1) those that destroy insects; (2) those that destroy weed seed; (3) those that destroy small rodents; (4) those that serve as game; and (5) those that serve as scavengers.

The value of birds as destroyers of insects is so well recognized today that little need be said here. The United States and Canada have long recognized the necessity of encouraging insectivorous birds and have passed laws giving them absolute protection Indeed it has been stated by a former chief of the United States Biological Survey that: "Without the birds not only would successful agriculture be impossible, but the destruction of the greater part of the vegetation would follow."

From the white grubs that live in the soil and cut off the roots of plants to the moths that flit over the tree tops, there are thousands of different kinds of insect enemies insidiously working and threatening to destroy the crops, the trees, the gardens, the very handiwork of man. But for each type of insect nature has devised certain birds which serve as a natural check upon their increase. There are the snipe and woodcock that probe the loose soil, the larks and the sparrows that scratch among the dead leaves and grasses, the warblers and vireos and wrens that scrutinize the foliage, the nuthatches and creepers that search the bark, the woodpeckers that drill for the borers, and the swallows and flycatchers that guard the air itself. Where insectivorous birds are numerous, it is a lucky insect that escapes, but where birds are scarce it is a fortunate plant that completes its life cycle in safety.

The second group of birds consists of those which derive all or a large part of their food from the seeds of weeds Some of them, like the tree sparrow and snow bunting, nest in the far north and are with us only during the winter months. Others, like the blackbirds and many of the sparrows are with us from early spring until late fall and feed upon seeds except during the nesting season. A conservative estimate of the seeds consumed by the tree sparrows alone each winter in New York State only has placed the total amount at over 900 tons. When, for one reason or another, a large number of seed eaters concentrate on a small area, they undoubtedly have a very beneficial effect on the weed pests of that region, but they would have to be ten times as numerous as they are to have any general effect on the annihilation of weeds the country over.

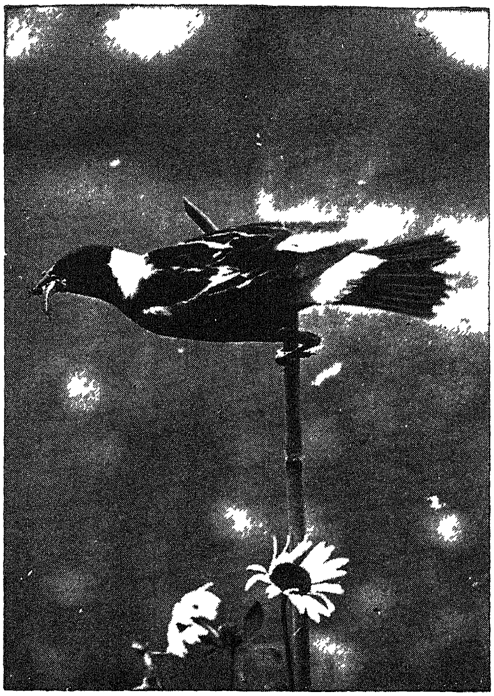
ONE OF MOTHER NATURE'S RAT TRAPS
A great horned owl and his prey.

The third way in which birds serve man is by the destruction of small rodents. Nearly every year during the deep snows, thousands of fruit trees, up to six and seven years of age, are girdled by meadow mice. At other times of the year the damage to grains and vegetables by rats and mice can hardly be estimated. These small rodents have from five to seven litters a year and from five to ten young at a litter. If all the young mice should live it would take less than five years for the offspring from each pair to number over three million. It is therefore necessary to have some natural control upon their numbers, and nature provides this in the hawks and owls. Indeed there are certain owls which regularly travel in flocks and seek out regions where the mice have become especially abundant, and they remain there until they have reduced them to normal numbers. Only one species of owl, the great horned owl, occasionally makes a nuisance of himself around the poultry yard or game farm and three species of hawks, the Cooper's, sharp-shinned and goshawk, regularly feed upon birds and poultry and should be done away with, but this is no excuse for putting all species under the ban, or for placing bounties upon their heads, as is often advised. We can afford to lose a few chickens and a few valuable birds rather than to be continually overrun with rats and mice and ground squirrels.

HUNTING CANVASBACKS
Some birds serve best as game.

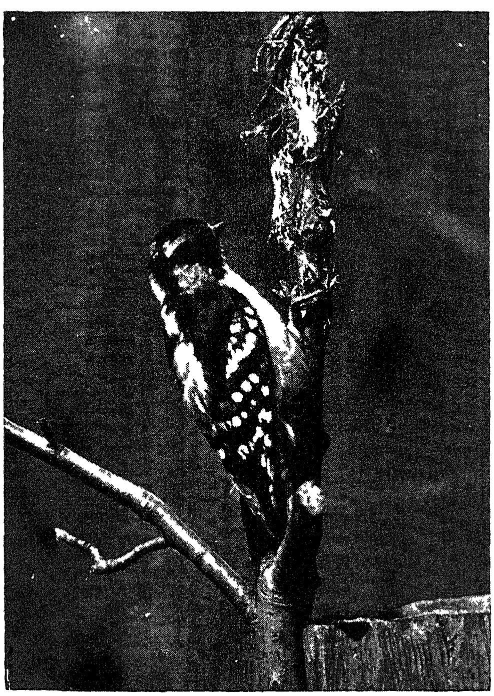
The fourth group of birds are those which serve man best as game. Thus we find that in New York State alone more than 500,000 persons have taken out hunting licenses in one year and have paid over one million dollars in fees, and yet this state is not noted for its game. There was a time not long ago, when any bird that was large

ALLIES AGAINST AGRICULTURE'S FOES



BOBOLINK
With army worm for its young

YELLOW-BILLED CUCKOO
With tent caterpillar for its young



DOWNY WOODPECKER AT WORK

A TREE SPARROW IS A WEED DESTROYER

enough to eat was considered a game bird and large numbers of robins, meadowlarks, flickers, killdeers and other insectivorous birds were sold in the markets. Today we realize that these birds serve man far better as destroyers of insects, and we limit our game birds to pheasants, grouse, quail and waterfowl which serve best in this capacity. As the number of hunters increases and the natural game covers decrease, the law makers and naturalists are presented with a new problem, that of maintaining the game supply against great odds. But laws alone cannot create game, and the business of producing large numbers of game birds either by properly maintained reservations or by game farms is becoming increasingly important.

ONE OF MOTHER NATURE'S SCAVENGERS
A turkey vulture sunning himself.

The fifth way in which birds serve man is as scavengers. The turkey vulture and the black vulture of the south, commonly called "buzzards", are ever present when carrion is to be disposed of and even a snake cannot die without being promptly discovered by them and devoured. In the north the crows and gulls perform a similar service in keeping dead animal matter from polluting the air. Especially about our harbors and shores are they needed, where the refuse from cities is thrown and where dead fish are continually thrown up by the waves, but they likewise often feed together long distances from water if a carcass is discovered that has not been properly cared for.

These five services which birds render us can scarcely be overestimated, but we are interested in birds not only for the good which they do but for the pleasure which they bring into our lives. Let us therefore consider the several means by which birds may be attracted to the house and garden.

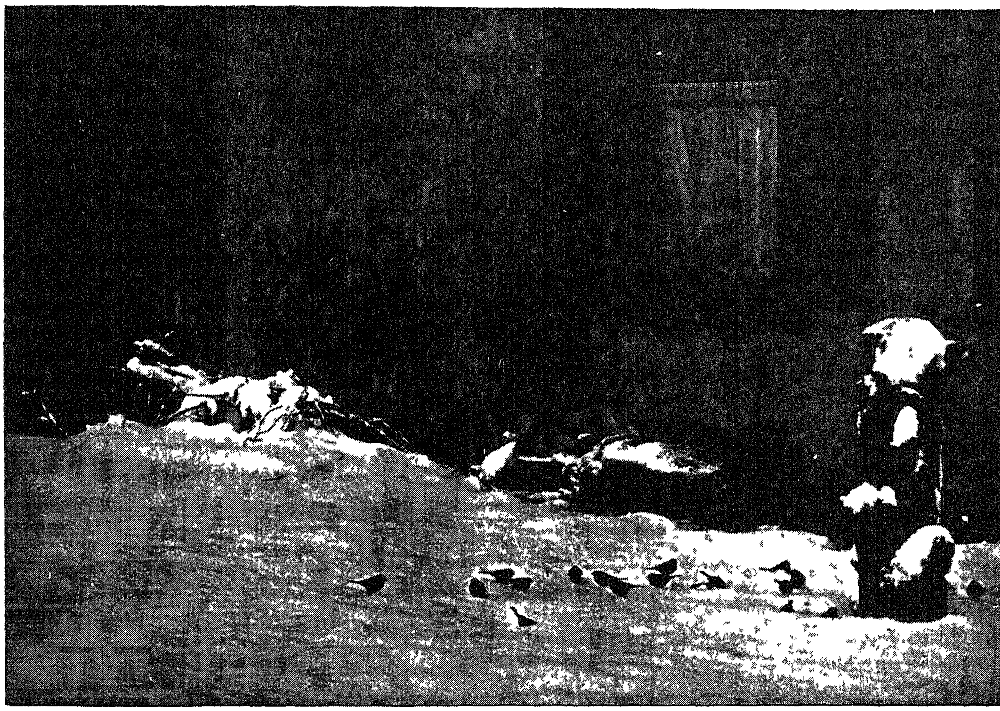
One of the simplest ways of attracting birds about one's home is by feeding them in winter.

The winter birds that may be expected to come to a feeding shelf are of two kinds — seed-eaters and insect-eaters. Among the seed-eaters in northern United States are the junco, the redpoll, the pine siskin, the crossbills, the grosbeaks, the song and tree sparrows and the blue jay. In southern United States one could also expect the white-throated, white-crowned and fox sparrows, the blackbirds and the cardinal, and in the Western States other species of finches and buntings. For seed-eating birds, good foods to use are millet, hemp, buckwheat and cracked grain of any sort, or, better still, mixed chicken feed, such as is sold for young chicks, sweepings from a neighboring mill, or hayseed from the barn floor.

Among the insect-eaters are the woodpeckers, the downy and hairy woodpeckers very widely distributed, the flicker, red-bellied and red-headed more common southward, the nuthatches, the chickadees and the brown creeper. The woodpeckers find their natural food by drilling into the chambers of wood-boring larvæ, the others find insects, pupæ or eggs in the crevices of the bark. All of them, however, are very fond of beef suet, and once they have found a piece fastened in the tree, they will return to it again and again until it is all gone. Sunflower seeds and crumbs of raw peanut are relished by both insect and seed-eating birds.

In placing the food it is well to bear in mind that eventually one wants all the birds coming to one place, either at a shelf at the window or to a place in the yard where it will be easy to watch them. It is well to select first the place where one wishes them to come, whether one immediately builds the shelf or not. Then, from this as a center, place the food along radiating lines to a considerable distance from the house. The more pieces of suet put up, the more quickly the birds will find it, and the sooner they will come to the window outer branches, by strings, small wire or twine baskets filled with suet. These baskets can easily be made from an ordinary piece of wire, as the size and shape are not important. Instead of using wire, some persons prefer to use a bag knitted from string and of such coarse mesh that the birds can easily peck through it. A half of a cocoanut shell makes a very satisfactory basket.

As soon as any of the birds have been seen eating the pieces of suet, it is time to put up the feeding shelf. This should



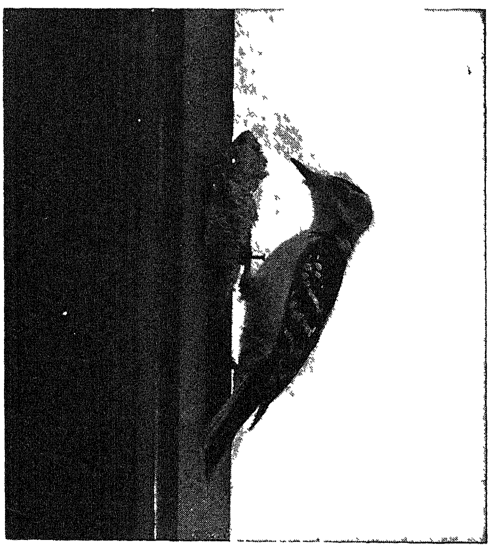
"WHEN A FELLER NEEDS A FRIEND"
Juncos, seed-eaters, waiting to be fed during a snowstorm.

sill, for birds are ever on the alert watching their fellows as well as searching for food on their own account. When one bird finds the suet, the others will see him and soon follow.

After the birds have found the suet it will be more economical to cover it with a piece of wire screening (one-half inch mesh) through which the smaller birds can peck. This precaution will keep the squirrels and crows from imposing upon one's hospitality and carrying the suet away in one piece. Another method is to suspend from the be placed at a window on the sheltered side of the house (usually the south), preferably the one nearest to a tree. If the window sill is very broad, it will be sufficient to nail a cleat along the outer edge to keep the food from blowing off. Usually, however, it is more satisfactory to fasten a board, from eight to twelve inches wide, to the sill to act as a shelf. It may be made the entire length of the window sill or only a part; but the larger it is, the more birds will feed together, for our native birds all want plenty of elbow room while

feeding. A narrow strip should be fastened to the edge of the shelf to keep the food from blowing off. At the westerly end a small evergreen tree or a large branch should be fastened. This offers shelter to the birds and proves as attractive as the food itself. It may be nailed to the window casing, or a hole may be bored in the shelf to hold it. It should be as large as can conveniently be held in place.

An even better device than the window shelf is the window feeding box. An ordinary soap box can be used and the bottom replaced by a pane of glass so as to admit plenty of light. One side is then rested on the window sill and the inner end



SUET ATTRACTS INSECTIVOROUS BIRDS
A hairy woodpecker on the window casing.

nailed to the casing, while the closed glass side faces the north and the box opens to the south. This box has the advantage of protecting the food from the snow and ice so that it is always available when most needed. Evergreen branches or a small tree fastened near by will increase its attractiveness. In many places house sparrows are so numerous that they will consume all of the food as fast as it is put out and leave none for the native birds so that it is necessary to find some way to curb their enthusiasm. A very simple yet effective way of protecting the food from their depredations is to hinge the front half of the floor of the box and support it at the corners by weak springs so that when a bird alights it bounces up and down. House sparrows are naturally so suspicious that when they feel the shelf give way beneath them, they lose no time in getting out of the way and never stop long enough to get any of the food. Our native birds, on the other hand, are unsuspicious and accustomed to feeding about the swaying branches of trees so that the more the shelf bounces, the more they seem to like it.

In case there is not a satisfactory window at which to feed the birds, this box can be placed on a post in the yard four or five feet from the ground. An evergreen tree, a bit of shrubbery or a pile of brush should be in the near vicinity to serve as a way station from the nearest trees, as most of the birds hesitate to fly long distances through the open, even to get food.

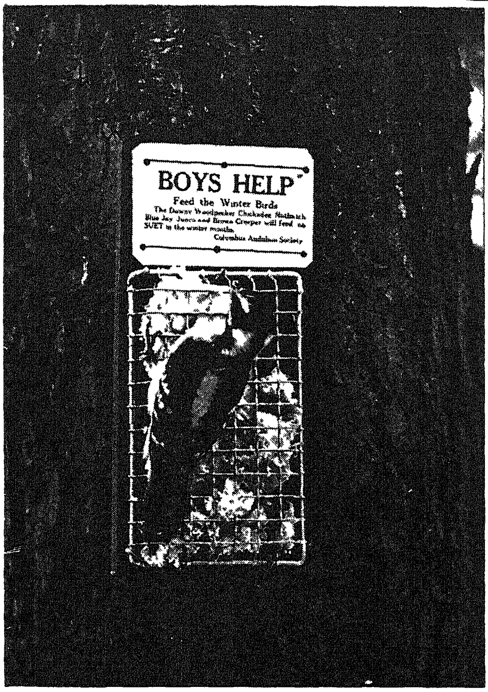
Another simple form of feeding shelf for such a place in the yard is made from the top of a keg or barrel, protected from the weather by a hood improvised from barrel hoops and a piece of white cloth and covered with a few evergreen twigs as here illustrated. The front half of this may likewise be hinged to keep away the sparrows, and it may rest on a pivot and be provided with wings like a weather vane so that it will always face away from the wind and snow. Various modifications of this device will undoubtedly occur to the reader.

If nothing but sparrows come to be fed, one should not be discouraged because they will act as decoys, and eventually their chirping will call other more desirable birds to the feast. One need not fear that they will drive the other birds away, for, next to the chickadee, the sparrow is the biggest coward of the lot, and often a single nuthatch will put a whole flock of them to rout.

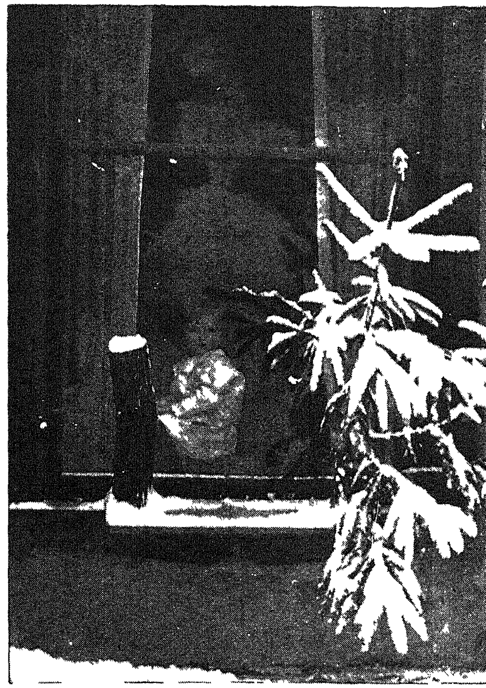
Another method of feeding birds is to plant patches of millet, hemp, buckwheat or sunflowers along the edge of the garden and let the birds do the harvesting.

Many hardy shrubs, vines and trees bear fruits which are attractive to birds and should be planted wherever birds are desired. The number of birds which depend upon fruits for their sustenance during part of the year, at least, is surprisingly

HOW TO FEED THE FEATHERED FRIENDS



CONVENIENT SUET HOLDER MADE FROM A SOAP DISH



THE WINDOW FEEDING SHELF AND BIRD'S CHRISTMAS TREE

ANTI-SPARROW WINDOW FEEDING BOX

EFFECTIVE HOME-MADE FEEDING TABLE

large and includes birds of almost every type from the woodpeckers to the thrushes, even the warblers, vireos and flycatchers being fond of some varieties.

In planting to supply fruit an effort should be made to select trees and shrubs with different fruiting periods, so that the supply will be more or less continuous.

If nothing but mulberry trees were planted, for example, the birds would have a surfeit during June, July and August, but would starve during September and October. If wild black or bird cherries are added, the birds will be provided for until November. The Virginia creeper and wild grape will hold their fruit through the entire winter, and the hackberry, the sumacs and the barberry practically throughout the year. These last mentioned, while not so attractive in the fall, when other fruits are available, are often the means of saving birds during the storms of early spring.

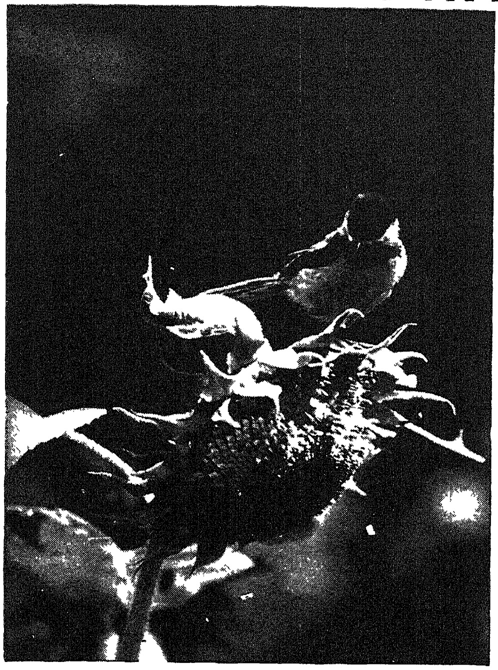
A strong argument in favor of planting the wild fruits is that of protecting the cultivated varieties. In some places the robins and waxwings do much damage to cherries, the catbirds and thrushes to berries, and the warblers to grapes, but in every case it is because there are insufficient native fruits in the neighborhood to supply their needs.

Below is appended a list of woody plants suitable for attracting birds. Those unmarked bear fruit relished by birds; those bearing an asterisk furnish also satisfactory nesting sites. The list is not complete, but even a superficial inspection of it will show how one may very easily select a wide range of shrubs and trees suitable for almost every kind of planting which will at the same time attract birds by their fruits and by the shelter which they afford. Care should be used to select none which would serve to spread fungus diseases, even though they may be very attractive to birds. The various species of currants and gooseberries (Ribes), for example, which are often highly recommended as supplying bird food, have been omitted from the list because they assist in spreading the dreaded pine blister. In wheat-raising districts, the barberry should be avoided likewise, because it harbors the intermediate stage of the wheat rust.

FRUIT-BEARING TREES AND SHRUBS ATTRACTIVE TO BIRDS

* Five-leaved ivy or Virginia creeper, August–February
Boston ivy, September–March
Red and black chokeberries, July–June
* Spicebush, July–November
* Japanese barberry (the berries are not often eaten when other fruits are abundant, but the shrubs furnish good nesting sites)
* Common barberry, July–June
Black or cherry birch
Yellow birch
White birch
Red birch (all the birches furnish food in fall and winter except the red or river birch, the fruit of which ripens from June to September)
Hackberry, January–December
* Dogwoods, June–March
White flowering dogwood (very desirable for its ornamental value, both in flowers and in fruits, as well as for bird food), August–January
Cornelian Cherry
* American hawthorns, October – April
* English hawthorn, August–March
Weigelia or Diervilla (the seeds are freely eaten in winter by slate-colored juncos, tree sparrows, redpolls and pine siskins)
Oleaster or wild olive, September–April
Gumi
Japanese oleaster (as soon as the fruit ripens in July it is attacked by robins, catbirds and cedar waxwings, and the tree is soon stripped)
Spindle tree (fruits are eaten by the myrtle warbler)
Wintergreen, January–December
Black huckleberry, July–October
Shrubby St. John's-wort (in winter slate-colored juncos, tree sparrows and redpolls are always found feeding on the minute seeds of this plant)
* Common juniper, January–December
* Irish juniper
* Red cedar (a favorite food of cedar waxwings and myrtle warblers), January–December
American and European larches
* Common privet, July–April
* Bush honeysuckles
* Japanese honeysuckle
* Morrow's honeysuckle (very attractive to birds)
* Ruprecht's honeysuckle
* Grapes, August–June
* Tartarian honeysuckle, July–April
* Matrimony vines
Partridge berry, January–December
Mulberries (one of the best bird foods), May–August
* Bayberry, or candle-berry (the best food to attract and hold the myrtle warblers), July–June
Sour gum or tupelo, July–October
White, black and Japanese spruces

PLANTS THAT ATTRACT AND PROTECT



CHICKADEE CONTEMPLATING AN INVESTIGATION
Sunflowers attract the chickadee, nuthatch and goldfinch.

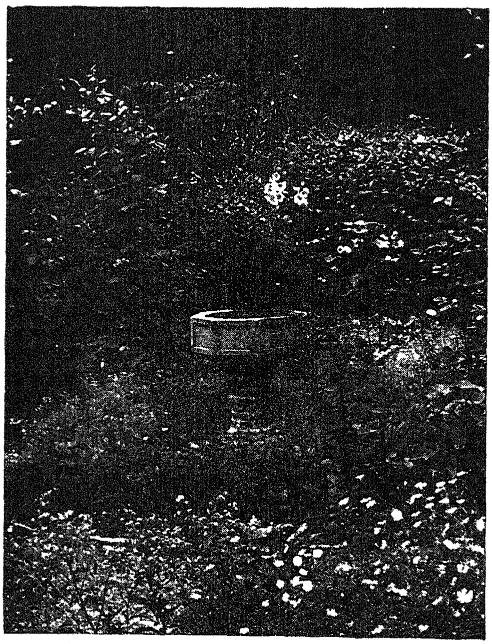
Photo by S. A Grimes

BLUE GROSBEAK FEEDING ITS YOUNG
Nesting in the protection of a white oak tree.

FEBRUARY ROBIN TOO EARLY RETURNED
The sumach saves the lives of robins and bluebirds that come north too early.

WAXWING ON A MULBERRY BRANCH
Mulberry trees protect the cherries from fruit-eating birds like the waxwing or "cherry bird".

Austrian pine
Red pine
White pine } (All the pines attract crossbills and grosbeaks)
Mahaleb cherry (the best of the wild-cherry bird foods), June–July
European bird cherry
Wild red or bird cherry, June–November
Sand cherry, June–August
Wild black cherry, July–November
* Flowering crab (the best winter food for cedar waxwings, robins, northern flickers, pheasants and pine and evening grosbeaks), September–June
* Buckthorn, August–April



AN ATTRACTIVE BIRD BATH IN A GARDEN

Fragrant sumac, January–December
Shining sumac, January–December
Smooth sumac, January–December
Staghorn sumac, January–December
* Blackberries and raspberries, June–October
* Black elderberry, July–October
Red elderberry, June–August
Sassafras, July–October
Buffalo berry, June–October
* Greenbrier, August–June
Nightshade, or bittersweet, July–April
Mountain ash (as the bright red berries hang on the trees, about Christmas time, these trees add to a winter landscape by their ornamental appearance. They also furnish very good bird food), July–April

Another method of attracting birds about one's garden is to have convenient for them a constant supply of fresh water. This may be offered in an elaborate bird fountain or bird bath built to correspond with other architectural features of a formal garden or it may be merely a shallow pan of water which is replenished from time to time. The principal thing to bear in mind is to place it so that the birds will not fall victims to preying cats when they are almost helpless with their soaked plumage.

Still another way of attracting birds about one's home is to build bird houses which are suitable for them to nest in.

There are over fifty species of birds in the United States and Canada which utilize holes in trees for nesting, including many of the most useful. The borer-destroying woodpeckers, the larvæ-destroying nuthatches, the egg-destroying chickadees, the mosquito-destroying tree swallows — all build in holes in trees and may be attracted to nesting boxes. In these days of scientific forestry when every dead tree is condemned and when every dead branch is lopped off by the "tree doctor", the birds' natural nesting sites are rapidly disappearing and their numbers must necessarily decrease unless they are provided with artificial nesting places. It is a wise timber owner who puts up at least one nesting box in the place of every dead tree which he removes. The chickadees and woodpeckers that are with us in winter and the wrens and bluebirds that return in the spring will move on unless they find plenty of nesting sites.

Of the hole-nesting birds, a comparatively small proportion have yet learned to accept the artificial nesting site, only nine species taking them regularly and nineteen more utilizing them occasionally. It is to be expected, however, that eventually all the species will learn to adapt themselves and perhaps even others will so modify their present nesting habits as to accept the artificial structures. This proved to be the case in the celebrated experiments of August von Berlepsch in Germany, where out of a thousand nesting boxes on his estate, birds gradually were induced to occupy over 900.

The species which regularly use nesting boxes are as follows: house wren (and all its sub-species), bluebird (eastern and

western), chickadee (northern and southern sub-species), purple martin, tree swallow, flicker, violet-green swallow, house-finch, Bewick's wren, house sparrow, and starling.

The species which occasionally use nesting boxes are as follows: white-breasted and red-breasted nuthatches, downy, hairy and red-headed woodpeckers, tufted titmouse, Carolina wren, crested flycatcher, screech, saw-whet and barn owls, sparrow, hawk, wood duck, song sparrow (rarely), and dipper. The species reported as using covered shelves or shelters, open at the sides, are robin, phœbe and barn swallow.

The best materials to select in building bird houses are weathered boards, rustic cedar, slabs of wood with the bark adhering, or asphaltum roofing paper. Smoothly planed boards and paint should be avoided except on such houses as are intended more for ornament than for use. Gourds, when obtainable, can be made very acceptable by cutting a hole of the proper size in one side, cleaning them out and drilling a small hole in the bottom to drain off any rain that may beat in. A hollow limb, a deserted woodpecker's nest, or a block of wood hollowed out in the form of a woodpecker's nest are all good devices, but usually it is easier to cut rough boards into proper lengths and nail them together securely in the form of a small box. Sometimes boxes of the proper size, such as chalk boxes or starch boxes, can be found ready made and require only some reinforcement If one plans to make a great many of standard size, heavy asphaltum roofing paper lends itself most readily at a minimum of expense.

Whatever material is used the exact size of the box is not of great importance except that it should not be so large as to waste material, nor yet so small as to give insufficient room for the nest. A box should never be smaller than $3\frac{1}{2}\times3\frac{1}{2}\times6$ inches inside measurement, and it is better to make it somewhat larger even for wrens. In making bird houses for the first time, it would be well to make them of average size, that they will be acceptable to the greatest variety of birds. In this way the chances of attracting them are increased. Such a box would measure about $4\times4\times9$ inches inside with the long axis vertical. If special effort is to be made to attract flickers, screech owls or sparrow hawks, boxes $6\frac{1}{2}\times6\frac{1}{2}\times24$ inches should be made. If purple martins are desired, a house of from 10 to 30 compartments should be constructed with each compartment 6 to 8 inches square. Rows of gourds tied to cross pieces and raised on poles will likewise attract martins and are extensively used in the South.

Photo N. Y. Zoological Society

SCREECH OWL

The *size* and *position* of the opening are much more important than the exact size of the box. A round hole is best and, except in martin houses, it should be cut above the middle line on one side only, and preferably about two inches from the top. All hole-nesting birds, except the martins, wish to be out of sight of the entrance while incubating. There should never be more than one entrance to the box, but if the box is very tightly built a $\frac{1}{4}$ inch hole may be drilled just beneath the roof for ventilation and another through the floor for drainage. These are unnecessary, however, and in natural nesting cavities, of course, never occur.

If one wishes to build houses for certain birds, the following table of proper diameters for the openings will be found valuable:

a $1\frac{1}{8}$ inches: house wren, Bewick's wren, Carolina wren, chickadee
b. $1\frac{1}{4}$ inches: white-breasted nuthatch, tufted titmouse.
c. $1\frac{1}{2}$ to $1\frac{5}{8}$ inches: bluebird, downy woodpecker, crested flycatcher, tree swallow, violet-green swallow.
d. $1\frac{3}{4}$ to 2 inches: red-headed and hairy woodpeckers
e. $3\frac{1}{2}$ inches: flicker, saw-whet owl, purple martin
f. 3 inches: screech owl, sparrow hawk.
g. $4\frac{1}{2}$ inches. barn owl, wood duck.

Nesting material

No nesting material in the form of straws, feathers or sticks should be placed in the box, since, if a prospective tenant finds nesting material in the box, he will usually consider it already occupied and move on. In flickers' and other woodpecker boxes, however, there should be placed in the bottom a couple of inches of ground cork or coarse sawdust mixed with a little earth because the woodpeckers build no nests and must have something to keep the eggs from rolling about.

Quite as important as the proper construction of the bird house is the selection of the place to put it. It is possible to put up ten or fifteen boxes and have nothing but house sparrows nesting in them, when, if properly placed, they would be occupied by wrens, chickadees, swallows or bluebirds. If several boxes are put up, they should be at least 25 feet apart and preferably farther or constant fighting will usually result until one of the tenants is evicted. If one examines the natural nesting places of any of these hole-nesting birds, he will find that with few exceptions, they are in open places in bright sunlight or light shade, and seldom among thick branches of a tree or in dense shade. The best place for the box, therefore, is on a pole, five to fifteen feet from the ground in an open space or at the edge of trees facing the open. An iron pipe, an inch or more in diameter and eight feet long, set in the ground two feet, makes an ideal location for a box as it likewise gives protection from cats and squirrels. A post on the porch or the unshaded side of the house will also serve if the box is made to face outward. The trunk of a large tree, several feet below the first branches, a telegraph pole or a high fence post are other places which will prove suitable, although perhaps not quite so satisfactory as the separate post. An excellent place for the large flicker or sparrow hawk box is the top of a dead tree, particularly if the smaller branches are cut away from around the box. Occasionally a wren or a nuthatch will use a box placed in the shade among the branches of a tree but such places, while appealing strongly to most people as highly desirable, should be avoided. House sparrows are the only birds that will regularly use boxes when so placed.

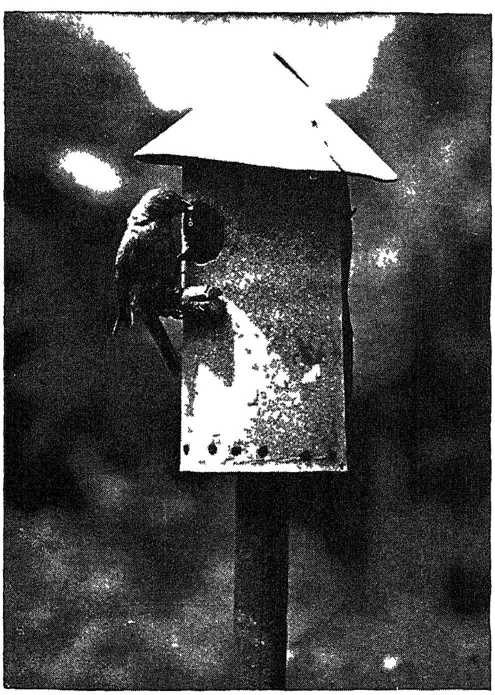
If a box is well made and once in position, it need never be removed, though it will probably last longer if taken inside during the winter. Frail or fancy boxes should be taken in each fall and replaced in March. Cleaning a box is not necessary under ordinary circumstances, as the birds will do their own renovation, but it is well to have the top or one side hinged, so that one can get at the inside if necessary, to throw out the nests of sparrows, or squirrels, or mice, or hornets that sometimes usurp the box before the birds arrive. Aside from this there is little need of care, and at the end of the season the old nests can be thrown out or left in, it making little difference to the birds when they return the following spring. The lice which often infest the nests of wrens are harmless and die soon after the young leave. If anything is to be done, the nests should be sprinkled with insect powder while still occupied.

The boxes should be in place as early as possible in the spring, especially those intended for nuthatches and chickadees that are with us throughout the winter. Although they do not begin nesting until April, chickadees often commence excavating their nesting cavities in February and it is probable that they have selected their nesting sites by this time. Boxes put up after the first of March and even as late as the first of May are sometimes occupied the same year but the chances are much better if they are put up early.

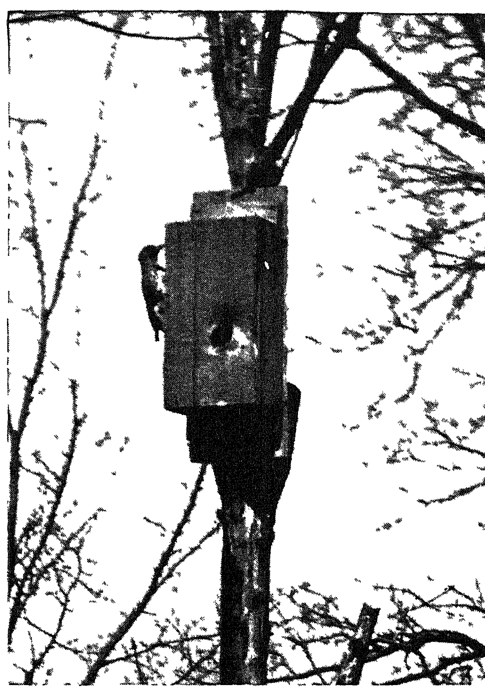
NEAT HOMES FOR PLEASANT NEIGHBORS

HOME-MADE WREN BOX WITH $1\frac{1}{8}$ INCH ENTRANCE FASTENED TO THE PORCH

PURPLE MARTINS DRIVING A SPARROW FROM THEIR COLONIAL BOX



BLUEBIRD BOX MADE OF ASPHALTUM ROOFING PAPER



WELL-PLACED FLICKER BOX IN A DEAD TREE

THE TRAVELS OF SOUND IN THE EAR

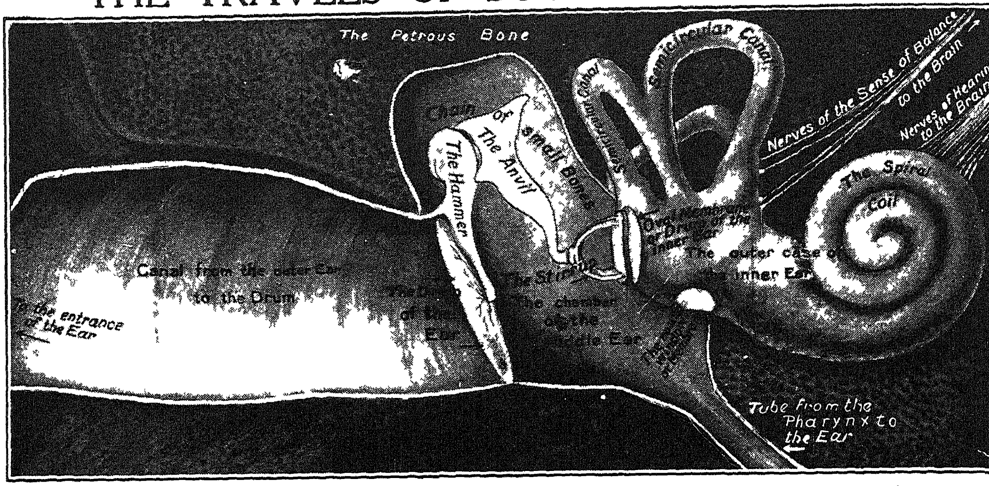
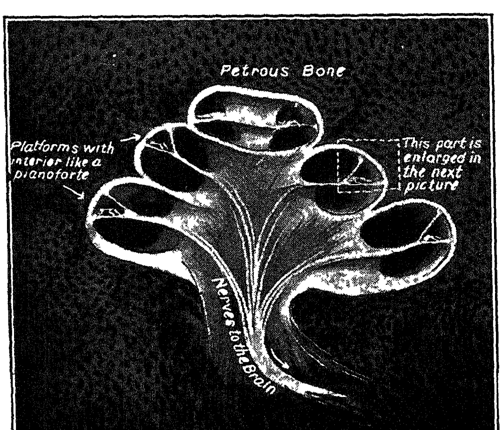
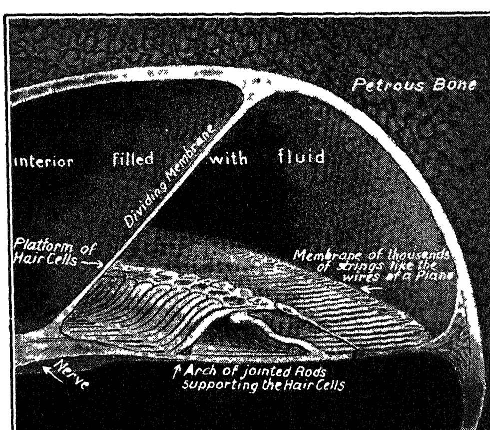


DIAGRAM OF THE CHAMBERS AND BONES OF THE OUTER, MIDDLE AND INNER EAR

DIAGRAM SHOWING THE PASSAGE OF A SOUND-WAVE FROM THE OUTER AIR TO THE AUDITORY NERVE



ENLARGED SECTION OF PART OF THE COCHLEA, WITH THE RECEPTIVE NERVES IN DETAIL



SECTION OF THE COCHLEA SHOWING THE INTERNAL DISTRIBUTION OF THE NERVES

THE WONDERS OF THE EAR

The Marvelous Adjustments of the Ear for its Multitudinous and Delicate Uses

DO WE THINK THROUGH SIGHT OR HEARING?

ON every ground we are justified in dividing the senses into higher and lower, and there is no doubt that vision and hearing stand together, with never a third, in the first category. They are higher because they are of later evolution. Probably all the qualities of sensation have been slowly evolved, in the immeasurable past, from some primitive obscure quality of sensation more of the nature of touch or pressure sensation, or perhaps from two qualities, one aroused by pressure and the other by chemical agents — this latter being the ancestor of modern taste and smell. Hence touch, taste and smell as we have them are historically more primitive in type than vision and hearing.

The question, like all questions in this realm of psychology, is of some æsthetic and ethical importance, for the claim is sometimes made that all the senses are necessarily of equal rank, and that therefore the pleasure of the palate, for instance, by the art of cooking, or the cultivation of the olfactory sense in certain decadent individuals, must be reckoned as on a par with the pleasures of painting and music.

To this the reply is that, historically considered, the senses are not equal. Nor are they equal when considered from the standpoint of their capacities. We must regard as higher those senses which have a great variety of possible qualities, and which afford us the largest measure of information about the external world, or of communication with our fellows. Thus judged, sight and hearing are obviously far higher than, say, the temperature sense, which has a very small variety of qualities, and affords us a very limited range of information.

Nevertheless, there is no doubt as to the very simple beginnings of the highest senses. Vision, with its infinite perceptive and creative possibilities, begins in simple sensibility to light, such as we find in many of the lowest forms of life. But living organisms have made incalculable use of this primitive capacity, until, in the highest animals and in ourselves, they have developed, as we have seen, special structures which not merely appreciate light, but can distinguish between the qualities of light of all colors. This subtle discrimination of color, achieved by means of the recently developed cones of the human retina, marks the level to which the primitive sense of light has attained.

There is here a close parallel with the ear and the sense of hearing. Historically, and even today, that may be called a pressure-sense. The physicists tell us that sound is simply a series of to-and-fro waves in the air, or some other medium, which reiteratedly bang away at the drums of the ears. It is essentially a series of taps, and nothing more. Vibrations made by a very large and heavy tuning-fork will excite waves in the air that may be just too infrequent to be heard, but are readily felt by the skin, and such an observation shows us at once the simple physical and psychological relation between the touch or pressure-sense, and hearing. Doubtless this pressure-sense must be as primitive and as early developed in the history of life as sensibility to light; indeed, the very earliest forms of life, developed in darkness, must have been sensitive to pressure.

Why the modern hearing is entitled to be grouped with the higher senses

But modern hearing is entitled to be called one of the higher senses, as compared with the primitive pressure-sense which is still illustrated in the surface of the skin, because of the great range of qualities and great powers of discrimination between them which this sense now exhibits. Apparently there is a close parallel between its recent development, culminating in man, and that of vision. Color in light corresponds to pitch in sound. In each case the scale depends upon the frequency of the respective waves. When the eye distinguishes colors it distinguishes wave-frequencies, and exactly the same is true of the ear when it distinguishes sounds. We have seen that the modern eye is marked by its capacity to distinguish colors, and that this depends upon the development of a comparatively recent structure, the cones of the retina. Just so do we find that the appreciation of pitch, upon which the possibility of music, to name nothing less, depends, is a recent development of the sense of hearing, and appears to depend upon the most recent structure in the ear, which is known as the organ of Corti, and is thus the aural parallel to the cones of the retina.

What the ear has lost and gained during its evolution

But in the case of the eye we did not reach the cones of the retina until we had traversed a very complicated apparatus for conduction and control of the waves of light. Similarly, before we reach the organ of Corti in the internal ear, we have to study a sound gathering and conducting apparatus. The ear has no lens by which the sound-waves, can be focussed just like light-waves, but it has an apparatus for gathering sound-waves which comes to much the same thing, and it also has muscular arrangements for controlling the intensity of sound, corresponding to the iris of the eye.

What we commonly call the ear is really simply a gathering device, markedly decadent in man, which cannot be controlled by him either for the better reception of sound or for the detection of its direction. It is true that the external ear is provided with three small muscles, but only a few people have voluntary control of them, and even those persons do not put them to any use. The reflex mechanism which would enable us to "cock" our ears has also fallen into desuetude This is merely one more of the many instances in which the body of man is decadent, and if we test his hearing quantitatively we may be tempted to regard this sense as inferior in him, compared with many of the lower animals. But, judged by what we have declared to be the only legitimate test, which is qualitative, the human ear is quite incomparable.

The external ear is not entirely negligible, however, for if it be experimentally filled with wax, except for an aperture corresponding to the canal which leads inwards from it, the hearing is somewhat dulled. But if we desire to estimate the direction of sound, we have no machinery now for the purpose, and can only compare the relative intensity of the sensations set up in the two ears. Long and careful experiment has shown that this alone is accountable for our appreciation of the direction of sound. It follows that we cannot distinguish between sounds made at the back of the neck or under the chin, if these be produced when we are blindfolded, for sound coming from such positions is equally well heard in both ears, and we are left without guidance.

The drum of the ear a genuine and designed drum

From the external ear a canal leads inwards until it is closed by a definite and unmistakable drum-head. The canal is lined with glands of a peculiar type, which secrete the wax of the ear, in order to keep the canal clean. The drum of the ear, or tympanum, is no more figuratively so named than the lens of the eye. It is what it is named, and those who can credit its origin by the natural selection of chance variations can credit anything. If this drum be looked at by the aid of a beam of light thrown into the auditory canal, a deep shadow is seen lying across it.

This is due to the first of a chain of three minute bones, the auditory ossicles, which are found in the middle ear. From their form these three bones are called the malleus, incus and stapes — the hammer, the anvil and the stirrup respectively; and they are jointed together as the diagram shows, so that they communicate between the outer wall of the middle ear, constituted by the tympanum, and its inner wall, which has a window, or opening, also closed by a membranous drum, to which the foot of the stirrup is attached.

The peculiar and special dangers of the air-filled middle ear

The middle ear is filled with air, by a special tube which runs from the pharynx. The oxygen from this is absorbed by the blood in the neighborhood and carbonic acid given out by a process of very subsidiary breathing comparable to that which we have seen in the lungs. Not only is this necessary but the pressure of the air must always be the same as that in the auditory canal, so that the drum of the ear having equal pressure on both sides can vibrate freely when sound-waves strike it.

This tube is a physiological necessity, but also a source of danger. It means a possible route of infection from the nose and throat. Thus microbes that have obtained a hold there, as in scarlet fever or measles, are very liable to travel up this Eustachian tube, as it is called, and to infect the middle ear. Short of that, inflammation of the throat is apt to close the Eustachian tubes, and so interfere with hearing, as we know in the case of a common cold. But actual middle-ear disease is a serious affair. It is very apt to lead to the perforation of the drum, an irreparable disaster, and it may involve the thin bony roof of the middle ear, upon which lies part of the brain itself. Hence the Eustachian tube is the route by which an infection of the throat may lead to inflammation of the lining of the brain, technically called meningitis, or to abscess in the brain itself. The practical moral of this is to enforce more attention to the hygiene of the nose and throat, especially in children, so susceptible to adenoids.

Air, bone and fluid each used in the ear as a conductor of sound

Inside the middle ear we find two muscles, one attached to the malleus, and called the tensor tympani; the other attached to the stapes, and called the stapedius. When the former is thrown into contraction it pulls upon the malleus, which is attached to the tympanum, so that the tympanum is tightened and made considerably more responsive to sound-waves striking it. This is the muscle which we throw into action when we strain to hear.

Not less important is the action of the stapedius, which is to damp down the vibrations of the bony chain, so that loud sounds are made less intense. One of the reasons why expected noises are so much less distressing, and why people cheerfully bang the door who resent other people's carelessness, is that the stapedius muscles in the two ears are thrown into anticipatory action. In certain injuries to the facial nerve, which sends a slip to the stapedius, this muscle is paralyzed, and then loud sounds are apt to be very painful — like a bright light thrown into eyes of which the iris has been paralyzed by belladonna or its active principle, the alkaloid atropine.

Apparently these arrangements for the control of sound furnish the chief or only reason for the existence of the middle ear. There is no doubt that the chain of bones through which these muscles act are the efficient conducting arrangement, for hearing is markedly impaired if the bones be destroyed by middle-ear disease, or even if the tiny, delicate joints between them be stiffened in old age.

The sound-waves passed through air in the auditory canal, through a chain of bones in the middle ear, and now they come to fluid, and are conducted in it, so that we actually hear sound-waves in water, as in the case of fish, where only an inner ear is developed. This fluid is contained in the inner ear, which is closed by the membrane to which the foot of the stapes is attached. The whole apparatus lies buried inside the hardest bone in the body: the rocky, or petrous, part of the temporal bone.

This extreme hardness of the temporal bone is probably a very great advantage from the point of view of sound conduction, and sound-waves can to some extent affect the inner ear by conduction from the teeth and through the bones of the head. When the temporal bone is examined, it is found to contain a double piece of apparatus, all of which is undoubtedly of the same evolutionary origin, and which appears to be supplied by one and the same nerve.

This auditory nerve, however, is now known to consist of two distinct parts, with different centers in the brain, but only one of these is really auditory. The other runs to the brain from what are called the semicircular canals, now known to be no part of the organ of hearing. They have a very important function, as we shall see, but it has nothing to do with hearing. Their structure plainly indicates that they are concerned with the direction of something, and the view was long held that they inform us as to the direction of sounds, but that is now known to be erroneous. They are our organs of equilibrium.

The primitive ear in animals which has been further developed in man

In invertebrate animals we find a sac, containing hard material, and called the otolith sac. In the fishes and all other vertebrates three semicircular canals are developed, and the otolith sac is divided into two. From one of these two portions there is developed, in reptiles, birds and mammals a spiral canal, like the shell of a snail, which is called the cochlea. This it is which has taken over, in ourselves, the whole of the function of hearing, and has developed within itself the extraordinary structure which is known as the organ of Corti, and corresponds to the retina of the eye. It is to be admitted, however, that the retina is really nothing less than brain, while the organ of Corti is developed from the surface of the body.

The cochlea consists of two and a half spiral turns round a central supporting pillar. But this spiral canal is subdivided by plates of bone and membrane into three staircases, or scalæ, as the early Italian anatomists called them.

The wonderful vibratory organ of the inner ear

Upon the membranous partition, which extends throughout the two and a half turns of the canal, we find the special structure called the organ of Corti. This is a very complicated arrangement of cells, placed upon a vast number of parallel fibers rather like piano wires, which are longer at the base of the cochlea, and gradually get shorter as the staircase across which they are stretched gets narrower. The resemblance between these regularly shortening fibers and the wires in a piano or other stringed instruments is too striking to be overlooked, and it has been supposed that these fibers act like the wires of a piano, responding to various vibrations that reach them, according to their length, and thus affecting the particular part of the organ of Corti which lies upon them.

In this organ itself the essential elements are the hair-cells of Corti, many thousand in number, which are long, plump cells, having fibers of the auditory nerve encircling their bases, while their upper ends are provided with several short, stiff hairs, bathed in the fluid that fills the cochlea. These are undoubtedly the all-important cells of the inner ear, and are to be looked upon as exactly corresponding to the rods and cones, or perhaps more especially to the cones, of the retina.

Where sound becomes changed to nerve impulses and the brain hears

Whatever may be thought of the resonance or piano theory, which was stated in its original form by the great German Helmholtz, it seems impossible not to suppose that the hairs of the hair-cells must have an important function, since we know that they are bathed in the very fluid in which the sound-waves are certainly transmitted.

Only prolonged microscopic study of the organ of Corti can give any real idea of its complexity, and the completeness of the arrangements which it comprises for the reception of sound-waves. Thus, for instance, there appears to be a membrane which damps down the vibrations after

they have passed the cells upon which they act, and it is also noteworthy that there are no blood-vessels in this organ, for undoubtedly the alterations in the blood-pressure would sadly interfere with hearing if there were. The nerve supply is extremely rich, and the ultimate fibers lose their sheaths and envelop the pointed ends of the hair-cells. It is at this point that we have to face the mystery which we met in the retina. Light goes no further than the rods and cones, and sound goes no further than the hair-cells of Corti. What travels to the brain through the auditory nerve is not sound, but nerve-impulses, and it is a further illustration of the "law of specific sensations" that by whatever means the auditory nerve may be stimulated, the result is sensations of sound.

The amazing and unexplained possibilities of the finest sense of hearing

Disturbances in the circulation in any part of the middle or inner ear, spasm of the tensor tympani or stapedius muscles, and other local causes are thus able to excite the auditory nerve, and the result is sound-sensation, just as pain follows any excitation of its specific nerves, and vision follows any excitation of the optic nerves.

Vastly complicated as the cochlea is, it affords us little clue to the astonishing possibilities of the sense of hearing, as they are exhibited by the trained musician. The ear of a good violinist can distinguish fifty distinct notes or levels of pitch between F and G in the middle of the piano. The range of the eye for light extends to rather less than one octave — *i.e.*, roughly, from about 400 to about 750 millions of millions of ether-waves in a second. The ear has a much wider range, extending considerably beyond the seven octaves of an ordinary piano in both directions. The lowest notes perceptible by the ear consist of about twelve to sixteen vibrations per second, and the highest, like the bat's squeak, run up to thirty-five or forty thousand. People of trained musical ear can distinguish more than twelve thousand separate notes or qualities of sensation between these two extremes.

Ever since the time of Helmholtz one theory has followed another in the attempt to explain how these thousands of different sensation-qualities are distinguished. There is much to be said for the piano or resonance theory, in one form or another, but much also to be said against it. Sound-waves are too large to answer at all well to the requirements of anything so tiny as the organ of Corti. Helmholtz was assured that, by some material mechanism of the many with which it is provided, it analyzes complex vibrations, such as nearly all sounds are made of, especially musical sounds, and so sends to the brain separate and distinct impulses to correspond to each part of, say, a musical chord.

The brain reached physically, but ineffectively, by direct sound

But it is impossible to maintain that the cochlea is capable of analyzing complex vibrations. All we can credit it with is extreme acuteness of perception, and the power of sending nerve-impulses which reach the brain *en masse*, so to say, and are dealt with by it. The nineteenth century did its best to furnish a mechanical explanation, but the laws of mechanics forbid any such explanation to suffice for the case of the cochlea. We must go back to the brain, where mechanics and every other department of physical science break down. There can be no doubt that it was not physically correct to say that sound stops at the cochlea, as light stops at the retina. In point of fact sound-vibrations must go right through the head, including the brain and the auditory center. This is the one case where a sensory stimulus actually strikes the sensory center.

The brain aroused only through the appointed mechanism of the ear

Vision, touch, smell, taste — all these are excluded from direct action on the brain, and the stimulus must do all it can at some remote nerve terminal. But sound-waves are not so excluded, and actually traverse the auditory center itself.

We might very reasonably suppose that the whole aural apparatus is therefore more or less of a superfluity, and that our ex-

planations of hearing should try to deal with the direct action of sound-waves upon the brain. But pathology quickly tells us that hearing is made impossible if the auditory apparatus breaks down in any way, and that the problem here is therefore the same, after all, as that of the other senses. If the auditory nerves be thrown out of action, the centers are found to be quite unaffected by the sound-waves which must pass through them. And the fact is not without a parallel, for it is known that the cerebral centers for touch-sensation are entirely insensitive when they themselves are touched. Only through the appointed nerves can any of these cerebral centers be aroused. It is therefore practically, though not physically, correct to say that sound stops at the cochlea as light does at the retina.

Fine appreciation of sound more remarkable than a sense of absolute pitch

We are thrown back on the auditory center and its properties if we desire to learn how the ear analyzes and identifies sounds. Anatomists may call the cochlea the "inner ear", but the real "inward ear", like the "inward eye", is to be found in the *cortex cerebri* alone. We have already observed the range of its capacities, but their quality has scarcely been suggested. Many musical people have what is called "absolute pitch", which means that they can identify the pitch of any musical note they hear. The brain can carry its memory of pitch so that the hearer can say, at once, and without calculation or thought, that the motor-horn in the street sounds A, or that a whistle is in F sharp, and so on.

But the study of acoustics shows that the ordinary qualities of ordinary ears are really more remarkable than this sense of absolute pitch. When we distinguish the same note sounded by a horn, an organ, a piano, a violin, a clarinet, a friend's voice and a second friend's voice, our ears prove themselves capable of distinguishing and identifying the minute "overtones", or "harmonics", which constitute the difference between these different sounds, all of which are of the same fundamental pitch.

Orchestral and choral conductors possess fineness of aural discrimination which is almost incredible, readily picking out a wrong note played by one of perhaps a hundred and twenty instrumentalists. Yet acoustics tell us that separate sound-waves from each instrument cannot possibly reach the ear when we hear an orchestral chord. When more notes than one are sounded simultaneously, the resulting wave-form is a complex product, which is none of its constituents, and yet is affected by each of them. But the ear is capable, so to speak, of reconstructing in its entirety the sound-wave which does not really exist at all as such, but only as a modifying factor in the complex blended wave which reaches the ear. It will be evident that, since a particle of air cannot be simultaneously moving in two different directions, what happens when two different waves travel through the same air is that neither wave can survive as such. They destroy each other, and produce something else. But from the features of that something else the musician's ear can readily reconstruct and imagine that it hears each or any of the waves which were destroyed in order to produce it. What, then, can we positively assert of the cortical center? For instance, must we begin by assuming that there is a separate process, a separate substance, or a separate cell, for each of the twelve thousand distinct aural sensations which a good ear can identify?

The appreciation of gradations of sound similar to that of gradations of color

The answer to this must be negative. There cannot be so many distinct processes, but there must be a much smaller number of distinct processes which blend with one another in varying proportions so as to produce all the different pure tones, twelve thousand or so in number, which a good ear can identify.

This is rendered the more probable by the very definite evidence of vision, when we saw that the infinite gradations of color which the eye can distinguish are dependent not upon a separate provision, somewhere, for every possible tint, but upon

the varying proportions in which a very few primary sensations are excited. Most students believe four will account for all the possibilities of color-vision, and no theory demands more than six. In the case of the ear the number must be larger, though probably not more than fifty. This, however, is a very small number compared with twelve thousand, and it seems necessary to believe that every note we can hear depends upon a blending of these primary pitch-sensations, each of which, perhaps, corresponds to some definite substance in the auditory center.

Musical discrimination dependent on the proportions of a few primary elements

Perhaps the best of the evidence which suggests that our musical discrimination depends upon so few primary elements is that:

"If each distinguishable tone were an elementary quality, we should expect that when the air is made to vibrate at a steadily increasing rate, as when a violinist runs his finger up the bowed string, or the length of a whistle-pipe is regularly diminished while its note is sounded, the pitch would rise by a series of steps from one elementary quality to another; but this is not the case, the transition is perfectly smooth and continuous. A concrete example will make this point clearer: If two elementary qualities are excited by 196 and 200 vibrations per second respectively and are just perceptibly different in pitch, then the tone excited by 198 vibrations per second should be identical in quality with either 196 or 200, it should be of one or other of these elementary qualities. But we know that it is identical with neither, for it is distinguishable from 194, from which 196 is not distinguishable, and it is distinguishable from 202, from which 200 is not distinguishable. The rise in pitch seems, in fact, to be perfectly continuous and the differences of pitch infinite in number; such continuous variation of quality indicates that, as in the case of the continuous changes of quality of the color-scale, the change is due to a continuous change in the proportion of two or more constituents of a complex."

The lack of satisfactory studies of the brains of the musical and non-musical

Thus the musician will see that the continuity of his sense of pitch, and his capacity to appreciate pitch at any level, and to hear perfectly no matter to what exact pitch his instruments are tuned, depend upon the fashion in which pitch is appreciated — by the proportions in which certain elementary pitch-sensations are blended. But so far it is impossible to say what are the "primary pitches", corresponding to the "primary colors" in color-vision.

Microscopic study of the auditory center in the temporal lobe of the *cortex cerebri* has hitherto shown very little. This area of cortex, which has such a distinctive function, is not markedly differentiated in cell-structure from the areas which surround it. For instance, we find no marked local peculiarities like the large pyramidal cells of the psycho-motor area. All we can say is that the extent of this area is large in man. There is no evidence as yet to show that its microscopic structure is peculiar in tone-deaf persons, who correspond to color-blind persons fairly closely, nor have we at the present time any comparative study of the cortex in non-musical and musical persons, and in very great musicians.

It will be for future ages to make these inquiries when a different state of public opinion enables students to have access to different types of brains, when their former owners have no further use for them. It can be asserted positively, however, that nowhere is inheritance of psychical characters more evident than in this realm, and further psychological analysis of the musical sense will probably enable us to assign Mendelian ratios to the inheritance of certain of its constituents.

The functions of the mechanism of the ear only those of a messenger

We saw that the functions of the retina, though that is historically a part of the brain, are very humble compared with those of the visual cortex, as it is often called for short. Just so is it with the auditory cortex and the organ of Corti.

The receptive organ plays no part in memory, perception or any creative process. It simply receives impressions, and sends nerve impulses accordingly. All the rest is done by the cortex. All memories of sounds are stored there; it is the seat of "absolute pitch" in those who possess it; and the unknown physical agents by which we distinguish pitch at all must have their seat there. It is the auditory cortex that is at work in dreams of hearing and in all forms of auditory hallucinations and delusions (as distinguished from singing in the ears and similar disturbances). When we "hear voices" inspiring us to do deeds like a Joan of Arc, or to write noble words, it is the auditory cortex, the real inward ear, that is involved, whatever the whole explanation of these facts may be.

The true *status* of the auditory cortex in relation to musical conception and creation is furnished by the celebrated instance of one of the greatest musicians that ever lived, Ludwig von Beethoven.

The auditory cortex of the brain the sole seat of musical memory

Of course, there are no grounds for the popular view that musicians compose at the piano. They may improvise or "play about" there, but the musician composes at his desk, just as an author writes. His auditory apparatus is not concerned in the least, but his auditory cortex is indispensable. In destruction of the auditory cortex all possibility of musical appreciation, let alone creation, vanishes.

Beethoven was early attacked with slight deafness, which gradually increased until, for many of his latter years, he was stone-deaf. It may be asked whether we can now say if this deafness was of central origin, in the cortex of the composer, or had its cause somewhere in the aural apparatus; and that question can be answered at any time, without the aid of any examination, from the simple fact that during those years of absolute deafness Beethoven was composing some of the noblest and most beautiful musical compositions in the whole literature of the art. Assuredly his auditory cortex was intact, and by means of it he was enabled to conceive and create melodies, harmonies and combinations of tone-color which he never heard at all, even though he sometimes conducted performances of them, and yet which, in some sense no less true, he must have heard incomparably.

It is to be observed, then, that the auditory cortex is not merely capable of recalling sounds or melodies, as when we think of a tune, and, so to speak, hum it mentally, but it is also capable of conceiving sounds and sound combinations which it has never heard and never can hear.

People who think by sight and people who think by sound

Recent researches have shown that the great majority of people can be classified in one or other of two psychological types, corresponding to the two great senses described in this and the preceding chapter. These classes sometimes are called the "visuals" and the "auditives" respectively. The "visuals" or visualizers seem to conduct the majority of their mental processes by visual symbolism. They "think in pictures"; their mental method is graphic. The majority of women belong to this group, and, of course, the majority of painters, sculptors, architects, decorators, engineers and mechanically gifted people. Such people readily apprehend space-relations, and can conceive new ones. If they possess this power in high degree, they may paint fine pictures, build new types of architecture, conceive new machines.

The auditives, on the other hand, think more in sounds and words, and not in pictures. They naturally include the musicians, the men of letters and the scientific and philosophic people. They are more numerous among men than among women. They notice things around them less, and are more commonly credited with being "absent-minded." If great development of either is rare, vastly rarer is great development of both in one and the same individual. Such individuals stand out as the few supreme examples of what we call versatility, and of these the most notable representative in the history of the world was Leonardo da Vinci.

THE EFFECTS OF ALCOHOL

An Outline of the Evidence that Alcohol Does Not Keep out, but Lets in, the Body's Enemies

THE STORY OF AN UNHOLY ALLIANCE

WE must now try to compress within a reasonably brief compass the results of the many investigations that have been made by exact methods into the actions of alcohol upon the body in health and disease. These investigations have resulted in a formidable body of knowledge, only the main outlines of which can here be presented.

Like chloroform, ether and a large number of allied substances, alcohol must be numbered among what are called the "protoplasmic poisons", the action of which is essentially toxic to all forms of protoplasm, or living matter. Even the yeast-plant is soon killed by the alcohol it produces, if that be allowed to accumulate. The action of alcohol upon green plants also can be definitely classed as toxic; and when we pass to the animal world, the results are the same. Alcohol acts as an antiseptic, by its action upon the microbes of putrefaction, and it thus ranks high as a preservative of all forms of corpses; but for the living body, upon whose cells it acts as upon the living cells we call microbes, its preservative action is naturally reversed. If we begin with the simplest animal cell, such as the amœba, this destructive action of alcohol, beginning with paralysis (perhaps after a brief stage of what simulates stimulation), is clearly shown. From this humblest we may pass to the highest form of animal life — that of our own bodies; and this extreme transition will be justified when we remember the astonishing resemblance between the free-swimming white cells of our own blood and the amœbæ of the ponds. In general, the reactions of these types of cell are notably similar, and it is so here.

The consequences are of the gravest. As we saw at the very beginning of our present study of health, the leucocytes, or white blood cells, are an important factor in defending the body against invasion by disease germs. In the presence of such foes as, say, the microbes of pneumonia or consumption, the number of leucocytes in the body increases; and, given the invasion, this multiplication of the leucocytes, which is known as leucocytosis, is a good omen for the patient, for though we call it a "symptom" of the disease it is really a demonstration of health, and the best promise for its return. Many years ago Professor Metchnikoff found, first by study of a minute creature called the water-flea, that these leucocytes attack and destroy microbes and other invaders of the body. Later he proved, at the Pasteur Institute — and his results have been repeatedly confirmed and amplified since — that alcohol, present in the blood even in surprisingly small quantities, paralyzes the leucocytes, so that they cannot do their work so well.

After giving an account of his long series of studies, Prof. Metchnikoff stated that "as a logical consequence of the experiments on the weakening of immunity under the influence of alcohol, it has been suggested that we must eschew this substance in the treatment of infectious diseases. . . . We must strongly insist on the danger of alcoholism with regard to resistance against disease-producing microbes."

Other investigations have added to Metchnikoff's study of the white corpuscles evidence of the share which other elements of the blood take in normal resistance to disease.

How the blood fights disease

Thus the plasma of the blood is able to produce chemical substances that deaden or kill the germs and is therefore called "bactericidal". This is supposed to aid the white corpuscles in devouring the bacteria. The blood also produces substances that oppose the germs or counteract the poisons they produce. These are called "antibodies" and "antitoxins". Diphtheria antitoxin is an example.

The red corpuscles also play an important part in defense in disease attacks as well as in health. Their efficiency depends upon their power to retain the pigment, hæmoglobin, upon which their absorption of oxygen in the lungs depends. When the chemical composition of these corpuscles is changed from normal, either by lack of proper nutriment or by poisons circulating in the blood, their power to hold this essential pigment is weakened and the body suffers from lack of nitrogen.

The evidence that alcohol lessens the power of resistance against disease

The effect of alcohol upon each of these factors in disease resistance has been investigated, and the trend of all the reports is that alcohol impairs one or more of these processes. As the Journal of the American Medical Association conservatively puts it, in substance, after reporting recent experimental evidence of the weakening effect of alcohol upon resistance: "Although the extent and constancy of the damage cannot yet be stated with mathematical precision, there is sufficient agreement between the latest researches and what preceded them to throw the burden of proof upon those who would defend the regular use of alcohol."

Artificially induced immunity against special diseases, such as typhoid fever, cholera and tetanus has recently been added to the list in which innoculation against smallpox was the pioneer and that against rabies the product of Louis Pasteur's genius. Reports from specialists in all these lines testify that greater difficulty, or even failure, is frequently encountered when they try to induce immunity in alcoholic subjects.

Concerning hydrophobia, Prof. Metchnikoff said the vaccinations against hydrophobia carried out on persons bitten by mad animals are almost always successful, but those cases in which the treatment does not stop the outbreak of the disease are most frequently observed in individuals addicted to alcohol.

A great decline in the use of alcohol as medicine

This knowledge of the unfavorable action of alcohol upon the body's powers of disease resistance has contributed to the marked decline in the use of alcohol in pneumonia, typhoid fever and other diseases in which it used to be given as a regular routine. It brought about a revolution in hospital practice as far back as the early years of this century. Thus in the nine-year period 1897–1906, the expenditure for alcoholic beverages in the Massachusetts General Hospital fell off 71 per cent.

The fact that brandy is not listed in the 11th edition of the United States Pharmacopœia, the standard for the principal drugs used for medicinal purposes in the United States, is further evidence of the declining place occupied by alcohol as a medicine in the opinion of those specialists best able to judge.

But while the alcohol bill in hospitals has fallen with a rush, the milk bill has steadily risen, and results steadily improve, both as regards the death-rate and the length of convalescence. This applies not merely to such "medical" diseases as pneumonia, but also to "surgical" diseases. As we have seen, in both alike the essential fact is the same — the fight between the body, and its defenders, on the one hand, and invading parasites on the other.

The proof from pneumonia statistics that alcohol is detrimental

In a scientific work it is necessary to appeal to evidence, and here we may briefly mention hospital experiments which have led the foremost members of the medical profession to adopt their present practice. In one instance, pneumonia patients or their relatives were given their choice as to whether they should have alcohol or not.

Every condition was made identical, in the two sets of patients thus chosen, except on this one score. Over a long period, and with a large number of cases, it was found that the death-rate was about 15 per cent higher in the patients who were treated with alcohol than in those who got none. Interesting questions of responsibility clearly arise when we come to appraise the usefulness of practitioners who still adhere to nineteenth century practice in this respect.

Former arguments for medical use of alcohol based on false supposition

One of the diseases in which the use of alcohol was thought to be necessary, and for which it was upheld by such prominent teachers of medicine as Sir Thomas Fraser of England, was fever. The argument, as taught by the English professor, who later definitely and unreservedly abandoned it in his practice, was that the body requires food in fever; that the process of digestion is difficult or even impossible in this condition of the blood, and that therefore we should give alcohol, which was believed to be a food, with the special virtue that it requires no digestion whatever, but can be absorbed as it is into the blood and from the blood by the tissues. So long as the major assumption was granted, this seemed sound argument; but, as we have seen, in the great hospitals, alcohol has nevertheless been abandoned and replaced by milk (which can easily be predigested outside the body), even in fever.

The reason for the change in practice is that the supposed food-value of alcohol has not been upheld by subsequent research. The drug is in part destroyed, but that, as we have seen, proves nothing. Careful experiment upon the heart, the condition of which is so important in all acute fevers, has shown that alcohol does *not* support its action, though sugar does. In fact, nothing is more notable in recent chemical physiology than the steadily increasing evidence in favor of sugar before decomposition, and against the characteristic product of that decomposition. As we already know enough to see, every food substance must either supply a necessary ingredient of the bodily composition, or it must be a source of energy, or it must somehow expedite necessary bodily processes. As regards the first of these possibilities, no one claims anything for alcohol. It may be found in minute traces in the abstainer's body, but only as an effete product. Nothing alive, other than the vinegar bacillus, tries to live upon it, except man. It does not occur in milk, except in that of the drinking human mother. It contains no nitrogen, and is thus incapable of forming a part of any living tissue. But, though it thus has no claims to rank with the proteins, it might supply energy, and thus be what is called a "protein-sparer", preventing the body from having actually to burn its proteins, in the absence of any cheaper fuel — as a householder might have to burn his piano and floors in the absence of coal and wood. But the evidence now available strongly suggests that alcohol cannot rank as a food of this class, for it does not reinforce the energies of muscular tissue, as the experimental study of alcohol and other substances perfused through isolated and surviving hearts, removed from animals first killed, has shown.

Alcohol not a source of energy because it lowers the temperature

Most notably, the claims of alcohol as a source of energy, whether muscular energy or heat energy, have to face the fact that this substance lowers the temperature of the body, instead of raising it. The so-called "protein-sparing" action of the drug has its logical explanation in its interference with the nutritive processes which involve the use of the protein and the fuel-foods. It is a general property of alcohol that it retards fermentation. This is doubtless the key to its action on living matter, since life, physically considered, is a series of fermentations. Now, the processes by which the body utilizes its food are all fermentative, and alcohol interferes with them at their very beginning by its action on those initial processes of fermentation by which the red cells of the blood give up to the tissues the oxygen they have gained from the lungs.

The direct interference by alcohol with the internal process of combustion

This action of alcohol upon the red cells of the blood is probably only one degree less important than its action on the white cells. The business of the hæmoglobin which gives the red cells their color is to form a loose compound with the oxygen it meets in the lungs, and this compound, known as oxy-hæmoglobin, is decomposed by ferment action wherever the tissues need it. But alcohol, like certain other substances, has the property of interfering with this sequence of events, so that the oxy-hæmoglobin is not readily decomposed, and thus the tissues are "starved in the midst of plenty" of oxygen. Hence one reason why alcohol lowers the temperature of the body — by its direct interference with the combustion whence the body derives its heat. Hence also we find that the habitual consumption of much alcohol, in cases where the stomach of the drinker is resistant and alcoholic dyspepsia does not supervene, usually leads to the accumulation of superfluous, unoxidized tissue in the body, and the drinker becomes obese. Certain alcoholic beverages, such as beer, contain small but definite amounts of food material which, if properly burnt up, would provide the body with heat and energy, but the alcohol which is taken with them interferes with their combustion, and consequently leads to the storing-up of unused material.

The new view of the action of fever on the body

The diminished production of heat may be of still further importance. We know definitely that the maintenance of the normal temperature of the body enables it to resist the attacks of microbes. We know also that when microbes have taken their hold upon the body it commonly raises its own temperature — with the production of what we call fever — for the purpose of aiding it in its resistance. Until recent times doctors have regarded fever as vicious in itself, and have opposed it by all manner of means, especially irrational ones, such as antifebrin, antipyrin and other drugs which lowered the temperature by a directly poisonous action upon the vital efforts which were raising it. We know now that such methods were disastrous. Furthermore, it has been proved by crucial experiment and observation that the various degenerative changes in the body, which used to be ascribed to fever, are not at all the results of the raised temperature of the body, but are toxic, the results of its poisoning.

Fever a part of the bodily reaction against poisons

If the poisoning be present, but the temperature kept down, these disastrous changes still occur. If the temperature be artificially raised, as in a Turkish bath, or internally raised in hysteria, in the absence of microbic poisoning, and be maintained for long periods even at levels which sound incredible, these degenerations do not occur. And we are now certain that fever is part of the bodily reaction against poisons, and is valuable on many accounts — as, for instance, that poisons will be more quickly burnt up in a hotter body.

It follows that a second argument for alcohol in fever, which was maintained as lately as twenty years ago by distinguished authorities, must be abandoned. They argued that alcohol was useful in lowering the temperature of fever. But now we see that any substance which tends to interfere with the normal production of the bodily heat tends, therefore, to lessen its powers of resistance to microbes. Thus we find that the action of alcohol upon the red cells of the blood has, in effect, the same result as its action upon the white cells, which we have already studied. Not only does it directly paralyze the defenders, but it interferes with the conditions under which alone, if they be not paralyzed, they can best do their work.

Further, it is notorious that alcohol dilates the superficial blood-vessels of the body — not merely those of the face only, but those of the body as a whole. By thus throwing a large amount of blood to the surface, which is in contact with the cool external world, it markedly increases the loss of heat from the body.

It thus strikes at the maintenance of the bodily temperature in two complementary ways: by interference with the production, and by acceleration of the loss of heat.

The effect of taking a dose of alcohol on a cold winter's night

A dose of alcohol on a cold night, when one leaves a warm room, thus makes one feel warm, which we call keeping out the cold, but which is really letting out the heat. The nerves of temperature, which are situated in the skin, cannot distinguish between these two opposites, but the body pays its price. We fancy that if we feel warm we *are* warm, but our judgments are superficial, as are all judgments based on mere sensation without reflection. If the terminals of the nerves of temperature be bathed in a large quantity of rapidly flowing blood, for a time we feel warm, and the warmer the more rapidly we cool. We thus have a complete explanation of the fact that the absorption of alcohol, with subsequent exposure to cold, so frequently results in pneumonia, which is still by far the most fatal of all acute diseases. The microbe of pneumonia is quite commonly found in the mouths of healthy persons, waiting for a breach in the defenses, a bout of intoxication on the part of the white garrison, or some other opportunity. The ingenuous amateur marches out into the night, fortified by a dose of whisky in order to keep out the cold. His idea of keeping out the cold is to give out as much heat as possible to the cold, and to interfere, as far as may be, with the production of any more heat; and in order to do the thing up brown he arranges for the paralysis of his leucocytes. It would be a poor sort of *pneumococcus* that did not take advantage of such a chance.

The significance under different circumstances of a decline in temperature

We know that there are drugs — lamentably few — which lower a high temperature by striking at the cause which has incited the body to produce more heat. Quinine in malaria is such a drug. It kills the parasites that make the fever necessary, and with their death it declines.

But to interfere with fever, while doing nothing to interfere with the activity of the microbes which have evoked it, is more akin to manslaughter than to medicine. Hence, the doctor of today who is abreast with the leaders of medical science, welcomes the decline of his patient's fever if he believes that this indicates the disappearance of the need for the fever; but as long as the need persists — a need which alcohol does nothing to remove — he desires to see the fever well maintained, and nothing alarms him more than the failure of the body to maintain it in such circumstances. He knows that the falling line of the temperature chart may mean either the destruction of the invaders or the failure of the defenses; and he will no longer be deceived into paralyzing the defenses with alcohol under the delusion that the decline in temperature thus caused indicates the destruction of the invaders.

The diminution of the white cells of the blood in alcohol consumers

The relations between alcohol and the fluid part of the blood are still, as a whole, quite unknown; but, indeed, physiology cannot yet pretend to have any more than a superficial knowledge of the chemistry of the blood, in which lie many great secrets still unlocked. But one important fact in regard to the white cells needs to be added. It is that, in those who regularly take considerable quantities of alcohol, the number of white cells in the blood is markedly diminished. We do not yet know how the chronic consumption of alcohol has this result, whether by increasing the death-rate of the leucocytes or by lowering their birth-rate in the blood-cell-forming tissues, such as the spleen, but our knowledge of the physiological effects of alcohol would suggest that it acts in both of these ways. This remarkable discovery leads us to expect that the mortality from microbic diseases in general, among the alcoholic part of any population, including even the regular moderate drinkers, will be definitely and constantly higher than among those who do not take alcohol. And this, indeed, is the established fact, confirming Metchnikoff's teaching.

The comparative immunity of the abstainer from illness

Other statistical evidence is abundant, and constantly increasing — uniformly in the same direction. Insurance records in the United States and elsewhere have clearly shown that the abstainer enjoys so high a degree of relative immunity from microbic diseases in especial that he lives, on the average, for several years longer than his fellows. The theory that this is, however, a pallid and worthless existence need only be countered by the further actuarial demonstration that, during his longer life, he suffers annually on the average, from several days' less illness.

In a careful investigation made of the records of forty-three life insurance companies in the United States and Canada, the policy-holders were divided into several classes. Those with a past history of heavy drinking who had reformed without treatment, showed a mortality rate 32 per cent higher than that of the general class. Those who took the equivalent of two glasses of bear or one glass of whisky a day, showed a mortality excess over that of the average policy-holder of 18 per cent. Former heavy drinkers who had not drunk heavily for five years before being insured had a death-rate of 40 per cent above the average. Those whose daily amount was four to six glasses of beer or two glasses of whisky prior to application, but who were accepted as insurance risks had a mortality 86 per cent in excess.

"This means," say Dr. Eugene L. Fisk and Professor Irving Fisher in "How to Live", "that steady drinkers who exceed two glasses of beer or one glass of whisky daily, are not, on the evidence, entitled to standard insurance, but should be charged heavy extra premium."

Alcohol not protective against consumption

Tuberculosis, the commonest and most deadly of all diseases, involves questions too large for discussion in this section, which deals only with personal hygiene; but the influence of alcohol upon the individual, in his personal relation to the tubercle bacillus, certainly concerns us here.

The better knowledge of alcohol has changed the idea formerly held that it was antagonistic to tuberculosis. It is now looked upon as one of the great predisposing factors in the production of both acute and chronic pulmonary tuberculosis; and it is generally accepted that in alcoholic patients tuberculosis is far more likely to assume an acute and generalized form than it is in the non-alcoholic patients; for, as Dr. Dickinson said: "We may conclude, and that confidently, that alcohol promotes tubercle, not because it begets the bacilli, but because it impairs the tissues and makes them ready to yield to the attacks of the parasites."

In France a few years ago the districts consuming the most alcohol were found to have the highest mortality from tuberculosis, alcohol apparently acting as a devitalizing agent, and rendering the person addicted to it a more easy prey to infection.

A few years ago the Phipps Institute, Philadelphia, for the treatment of tuberculosis, published statistics covering a period of two years showing the difference in response to treatment between non-alcoholics and alcoholics, defined as "those who had used enough alcohol to do themselves some physical harm". The improvement was from 30 to 50 per cent greater in the non-alcoholics than in the alcoholics. The mortality in the two years averaged nearly 140 per cent higher in the alcoholics than in the non-alcoholics. The mortality among those having alcoholism in the preceding generation was 80 per cent higher than in those who had no such family history.

It is now known that pure air and good food are the all-important requirements in the battle for recovery from tuberculosis. Alcoholic liquors are liable to disorder the digestion, upon which so much depends. Pure air with rest, and occasionally a little exercise, as much as can be borne without fatigue, are the best stimulants to appetite.

Dr. S. A. Knopf, the New York specialist on tuberculosis, says: "Alcohol has never, and never will, cure tuberculosis. It will either prevent or retard recovery."

Resolution of the International Congress on tuberculosis in regard to alcoholism

These conclusions have been extended and confirmed in later years. The International Congress on Tuberculosis, when it met in Paris, passed a unanimous resolution to the effect that the fight against tuberculosis must everywhere be combined with the fight against alcoholism. At a later meeting in Rome, a great quantity of additional evidence was forthcoming, not least from unfortunate Italy, where the rise of industrialism and the concentration in cities have given great opportunities to the allied forces of alcoholism and tuberculosis.

The liability to cancer definitely increased by taking alcohol

A very remarkable indication of the subtle action of alcohol upon the chemistry of the body has been furnished from the study of cancer. This terrible and still imperfectly understood disease essentially consists of the development of "cannibal cells" from and in the cells of the body, in which an internecine and usually fatal war is then waged. Though these rebel cells act in all cardinal respects like parasites, cancer is almost certainly *not* due to a microbe or parasite of external origin at all. The relations of alcohol to this disease might therefore very well be wholly different from those which obtain in the case of the vast majority of all forms of disease. But careful study has shown that, other things being equal, the liability to the development of cancer is definitely increased by the consumption of alcohol.

The greater frequency of cancer of the alimentary canal in men engaged in occupations that encourage alcoholic indulgence is one indication of an influence exerted by alcohol. At first sight this appears to mean that the customary presence of alcohol in the tissues — and we know that the regular drinker is constantly under its action, for a single dose is operative for more than thirty hours — leads to the change of type which occurs when normal cells become cancerous.

Self-cured cancer and consumption more frequent than we realize

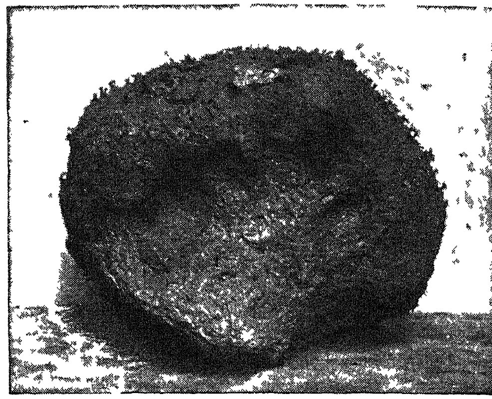
The present writer is strongly of opinion that that is not the true explanation, for many difficulties stand in the way of its acceptance — notably its failure to explain the *local* character of the disease. But, as modern students of cancer are now demonstrating, that disease occurs, like consumption, far more frequently than we used to suppose, and probably by far the greater number of cases undergo a natural cure. The local development is due to local causes, acting how we cannot yet say, and then the question is whether the rest of the body will resist successfully or not. If it be successful, nothing more is heard — probably nothing was ever heard — of the disease. We know no more of it than most of us do of the fact that we carry healed tubercle in our lungs and elsewhere. The silent forces of the bodily resistance have simply done their work; and there is some reason to suppose that in cancer, as in other cases, the leucocytes do great service on behalf of the body.

However that may be, the teaching of today is that the body's resistance is what, above all, matters, not in one disease, or two or twenty, but in *all*. Microbes and parasites of all sorts attack us, and the question is whether we can resist them. Our own cells turn parasitic, and the question is the same. We unknowingly take non-microbic poisons, such as lead, if we work with that metal, and the question is the same.

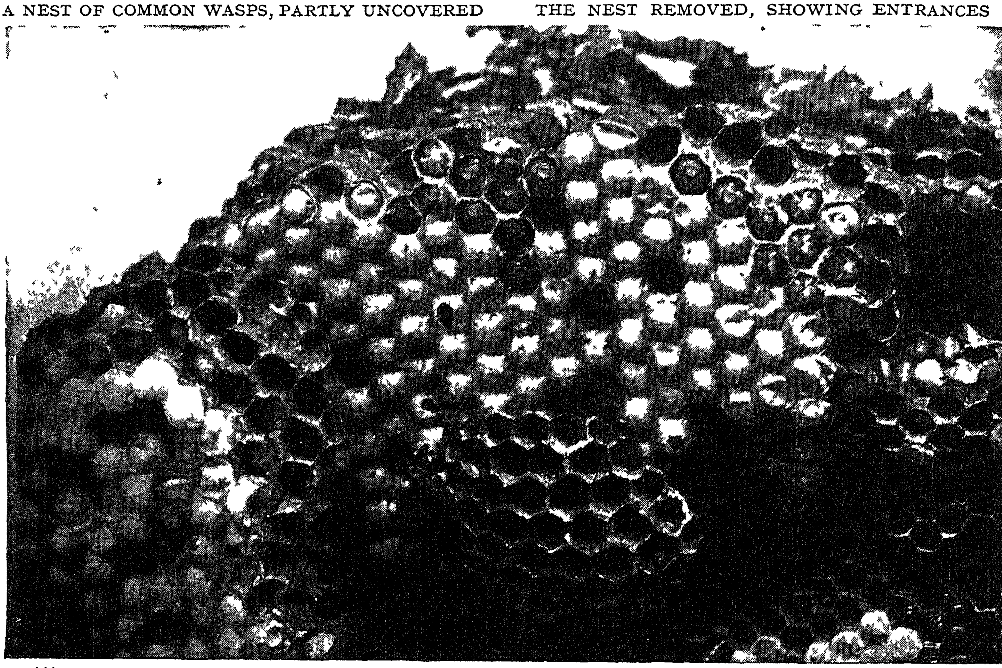
In all of these types of cases, which cover between them practically all the ills that flesh is heir to, alcohol has been proved to lower resistance. The white blood-cells may or may not be concerned, but always some cells or other are concerned, and the essential action of alcohol on all living cells, animal or vegetable, is the same. We have seen how it affects cells of relatively low type, like the leucocytes. In the next chapter we shall see how it affects the cells and functions of the brain; and elsewhere — for the subject is not part of personal hygiene — we shall see how it affects the germ-cells.

THE WASP'S HOME INSIDE AND OUTSIDE

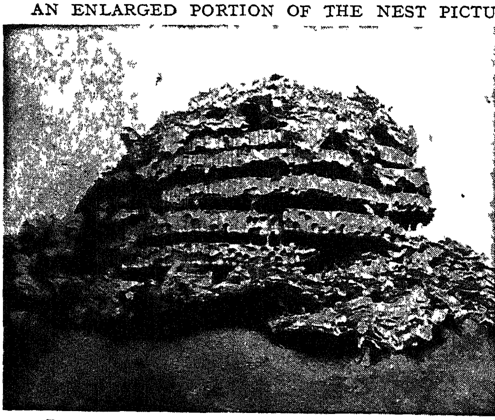
A NEST OF COMMON WASPS, PARTLY UNCOVERED



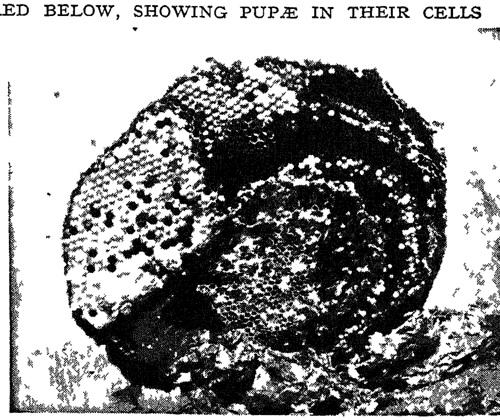
THE NEST REMOVED, SHOWING ENTRANCES



AN ENLARGED PORTION OF THE NEST PICTURED BELOW, SHOWING PUPÆ IN THEIR CELLS



THE TIERS OF CELL-LAYERS IN A NEST



THE UNDER SIDE OF ONE LAYER OF CELLS

ANTS, BEES AND WASPS

The Unapproached Marvels of Combination and Organization in the Insect World

SOME ROMANCES IN EARTH AND HIVE

IT is a striking and puzzling fact that to find in the animal world any sort of parallel to the life of civilized man we have to seek, not among the animals physically most highly organized, but among the insects Nowhere in the kingdom of nature outside the family of man do we discover anything approaching the miracle of efficiency revealed in a common ant-hill or beehive. The feats of the beaver are impressive, the union of forces among certain of the baboons, the coöperative hunting of certain members of the dog tribe, are features not lightly to be dismissed; but, with all said, there is nothing in the animal world which really challenges comparison with the husbandry, harvesting, cattle-keeping, wars and slave-making of the ants; nothing even faintly rivaling the perfectly ordered system of the beehive.

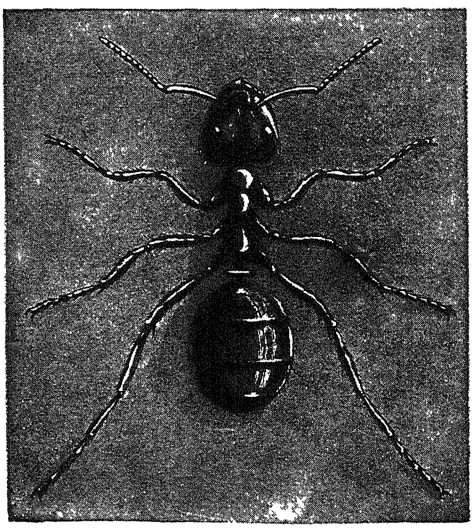
By what process these insects have advanced to this extraordinary development of communal life we do not know. Whether existing conditions indicate the operation of reason, or whether they arise simply as the outcome of obedience to blind instinct in insects, we do not know. This is not the place in which to attempt an answer to the problem which the united efforts of men who have devoted lifetimes to the study have failed to solve. Auguste Forel holds that certain insects may — possibly do — possess sixth and seventh senses of which we know nothing; Sir John Lubbock believed with Darwin that they are gifted with a "dose of reason". On the other hand, there are the skeptics who sniff with incredulity at the results of careful experiments by such men, begun before some such critics were born, and continued after they had written their theories Only by laborious personal investigation can the man who would grapple the mystery decide for himself to which side he shall incline.

The insects named at the head of this chapter are all members of the important order of Hymenoptera, four-winged insects, which include saw-flies, wood-borers, galls and parasitic wasps, ichneumons, spider-killing wasps, solitary and social wasps and solitary and social bees. Between 30,000 and 40,000 species are already known and it is conjectured that four or five times as many remain to be named. It will be noted that, while a main characteristic of the order is the possession of four wings, the majority of ants have no wings This, however, is the outcome of specialization which has given the ant world a unique place in the animal kingdom. There are three different forms of ants — the queen-ants and the male ants, both of which possess wings; and the neuter, wingless workers, which enormously preponderate

An ant colony may be formed either by a solitary queen or by several queens. Within her native home the young queen, in company with other queens, winged males and workers, has shared the common lot and labors of the establishment. She has stored immense reserves of energy within her little frame, and upon the appointed day soars in the air, which becomes blackened with the queens and males of other colonies. It is her first flight, and her last. She returns to earth to begin her nursery duties. The males set out upon

the same day as the queens, and their career ends within a few hours of the flight from the nest. They die that day; they may be destroyed by larger enemies, or they may sink to earth, to die by the wayside. They never return to the nest. Their part in life is played, and with them, as with the drones of the beehive, the curtain is rung down the day that it rises upon their career. The future lies with the queen and the workers.

Chance, so far as we can see, dictates to some extent the future of the queen. She may seek an establishment in which other fertilized queens are already in residence; she may be carried by workers to such a home; or she may select a suitable isolated spot, and there create her own little dwelling. Should the latter be the course, she must patiently await the maturing of her eggs, the slow development of her firstlings, which in this case appear as small though otherwise normal workers, who will take over from her the duty of tending succeeding eggs and young. In circumstances such as these the queen-ant is said not to leave the nest which she makes, but to subsist upon the reserves of tissue built up by her abundant feeding during her time in the nest from which she emerged. She must feed the larvæ with salivary secretions, and, out of her own substance, keep the little family going until the first brood are ready to forage for her. The workers now rapidly extend the city. They make tunnels and chambers in all directions, upon a methodical plan. The proceedings are practically identical with those in which workers are from the first installed. In either event the queen, who has left the parental nest winged and light as air, begins her serious work in life wingless.

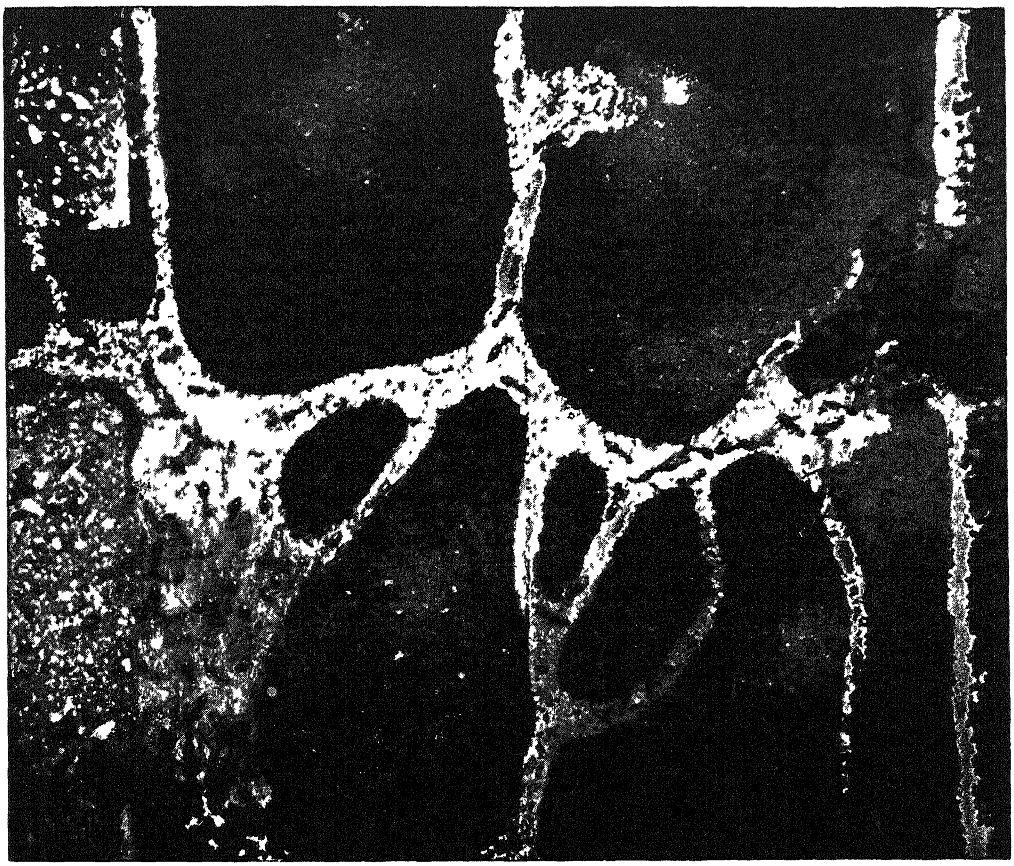


THE WOOD-ANT, HIGHLY MAGNIFIED

Upon her descent to earth, if she be alone, she either bites or breaks off her wings. In the case of one which descends in the midst of workers, the latter may relieve her of all temptation to further flight by themselves biting off her wings. With these workers about her, the now terrestrial insect is in good case. She may eat her fill of the food which the workers bring in. They take the eggs as she lays them, place them in nurseries, carry them from day to day from one gallery to another, even bringing them out of the nest into the sunshine, then restoring them to an underground gallery at night, so that throughout their period of incubation the eggs shall receive due measure of heat and moisture. The eggs hatch, according to the nature of the season, in from fourteen to thirty or even forty days. Small, white fleshy grubs emerge, legless, conical in outline. They are quite helpless, of course, and have to be fed by the workers with food which the latter present in a semi-digested form. Here again the nature, and even the period, of the season determines the rate of growth. While under favorable conditions the larvæ may reach the chrysalis form in the course of a month or six weeks, some species live through the winter in this stage, requiring the unremitting attention of their nurses throughout that period.

The chrysalis may be either naked or it may be invested in a neat silken cocoon. The ants' eggs of commerce, by the way, are merely the cocoon-clad pupæ of ants, not the eggs, which are tiny, yellowish-white objects. Needless to say, the pupa or chrysalis takes no food. The feeding is done in the larval stage; and the seemingly miraculous transformation effected within the pupa-case is wrought as the result of nourishment already assimilated. A shapeless grub begins the transformation; a per-

fect insect, fully grown, emerges. It is interesting to note that the new-comer cannot divest itself of its pupal cloak without assistance. It must be helped to freedom by the workers, who relieve it of its covering, straighten out its limp little limbs, wash and smooth and brush it with all imaginable tenderness, and, when it is able to trot about unassisted, apparently teach it its duties in the nest and beyond, setting it to tidy and garnish, to fare forth and hunt, marking out the dangers which it should avoid, etc. — a whole string of romantic "impossibilities" having been proved realities by observers of scrupulous precision.



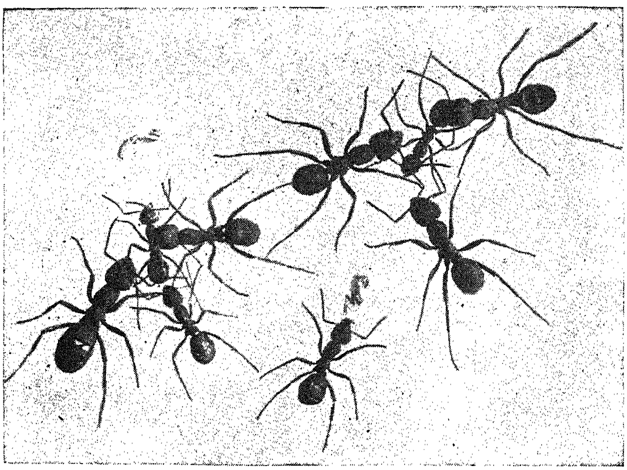
A SECTION THROUGH A NEST OF BLACK ANTS, SHOWING PARALLEL PASSAGES

The fact that this instruction is given seems to indicate that the work of these insects springs from instinct and from intelligence too. Instinctive actions are performed without previous training, as the result of a given stimulus. If the actions of ants were simply instinctive, the young ones would not need direction from the adults. It is arguable that the mere imparting of instruction by the adult workers is in itself an instinctive impulse But where there is apparently selection for duty in the highly complicated economy of the nest, we may perhaps assume that more than instinct is at work behind the selective process. The whole daily round of the life of the ant seems against the assertion that instinct alone guides, impels and controls.

The marvels of that life, and the inference to be deduced from it, are put in a nutshell by Sir John Lubbock: "When we see an ant-hill, tenanted by thousands of industrious inhabitants, excavating chambers, forming tunnels, making roads, guarding their home, gathering food, feeding the young, tending their domestic animals, each one fulfilling its duties without con-

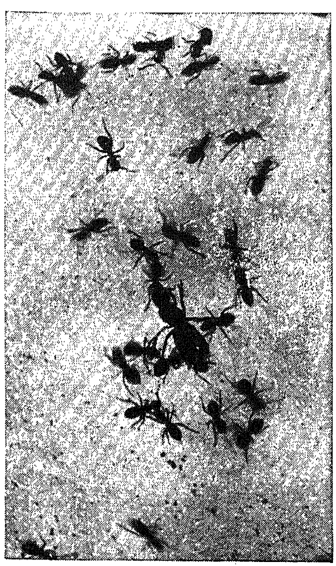
fusion, it is difficult altogether to deny them the gift of reason; and the preceding observations tend to confirm the opinion that their mental powers differ from those of men not so much in kind as in degree."

Upon what is such a claim to be based, if we would prove that an ant is capable of acting intelligently in new circumstances, in which there can be hardly any question of the play of unassisted instinct? Lubbock submitted his ants to many experiments, and that upon which he most relied he himself has described: "My principal experiment was one in which I placed intoxicated ants (he anæsthetized them with chloroform) near a nest, thirty-eight being friends and forty strangers to the colony. Of the friends, twenty-seven were taken into the nest and carefully tended; seven were dropped into the moat surrounding it, and four were left alone. Of the strangers, thirty were dropped into the water, one was left alone, and nine were taken into the nest. Of the latter, seven were again removed from the nest and carried to the water. Could anything more clearly show the reasoning power of ants?"



SLAVE-MAKING ANTS KILLING THE SMALLER BLACK ANTS AND CARRYING OFF THEIR PUPÆ

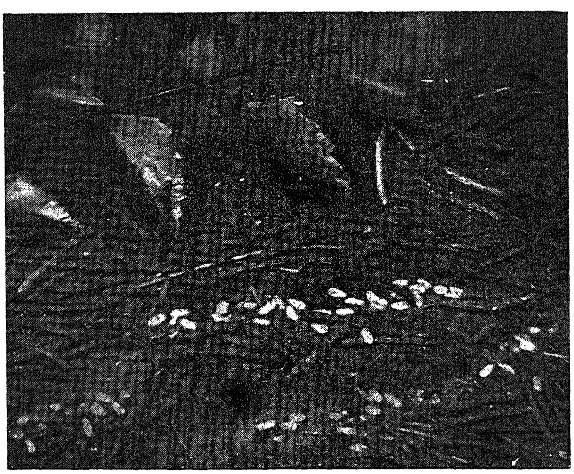
By what means ant recognizes ant we do not know. It cannot be the power of smell alone, though that sense, which resides in the inestimably sensitive antennæ, is undoubtedly of great assistance for this purpose, as for the detection of food and for finding the way back to the nest. But it cannot be olfactory evidence alone, for ants resulting from eggs taken from one nest and hatched in another are rapturously welcomed upon being introduced as adult insects into their native home; while their foster mothers, if put in with them, are at once destroyed. Possibly we shall never solve all the problems by which the life of these wonderful insects is complicated. We do not yet know all the senses by which they are actuated. It has never been proved that ants or bees *hear*. The voice of the ant no one pretends to have detected, but we all think that we know something of the language of the hive, and fancy that the sounds which we hear there are heard also by the bees. But, as Auguste M. Forel points out, no one has ever detected the auditory organism of a bee, removed it, and proved the insect afterwards deaf. That ants and bees do communicate one with another is as certain as that they live, but it may be the result of tactile impressions; wireless telegraphy may have been in existence in ant-hill and beehive ever since ants and bees reached their present stage of development. If, then, we cannot be certain upon this and similar points, it would seem impossible for us to speak dogmatically with regard to other aspects of lowly life. The progress of science soon makes any finality of statement absurd.



BLACK ANTS MOURNING A DEAD QUEEN

Something higher than instinct seems to be demanded for an insect which keeps and milks cows! This feature of ant life is one of the most clearly established in natural history. It is practised by more than one species of ants. The aphis, or plant louse, which deposits honey-dew upon the foliage or stems of vegetation, is the cow of the ant. In some cases the ants construct tunnels along the trunk of the tree or shrub which harbors the aphides, and in these tunnels form stables from which the "cows" cannot escape. In others, the honey-yielders are carried down into the ants' nest, and carefully maintained there. But the crowning wonder is that the ants purloin the eggs of aphides, carry them down into their nests, store and tend them during the winter as they store and tend their own, and, when the larvæ hatch, feed them as they feed ant larvæ, and eventually carry them into the open, and place them upon the very plant which constitutes the food of the aphis. And the reward for all this is that the ant obtains the honeyed secretion of the aphis, which it "milks" by gently stroking it with its antennæ, quite after the manner of man.

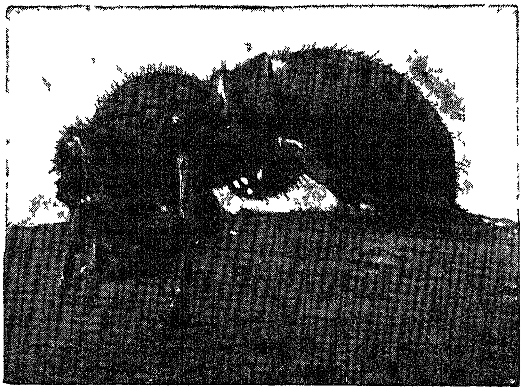

THE CHAMBERS AND PASSAGES OF AN EXPOSED BLACK ANTS' NEST


A SECTION THROUGH A PORTION OF A WOOD-ANTS' NEST, SHOWING COCOONS AND LARVÆ

The ant colony may contain various other forms of insect life, which are represented as the pets and playthings of the owners of the city. That is as may be; it is not at all unlikely that the so-called pets are harmless parasites, flourishing upon the food supply of their hosts, who tolerate them because of their harmlessness. That they *are* tolerated is plain, for in an instant a colony of ants, with their deadly jaws and lethal equipment of formic acid, could rid their home of every intruder within it. The idea of plaything is, of course, not wholly to be disregarded, for in nothing do ants more closely resemble man than in their apparent love of play. They leap and wrestle and gambol, with the ardor and sportiveness of children or kittens. They seem to show grief and solicitude for the injured and ailing, and, in the case of their queen, apparently mourn beside her dead body for weeks; whereas the dead body of a worker is at once removed, and buried at a distance from the nest.

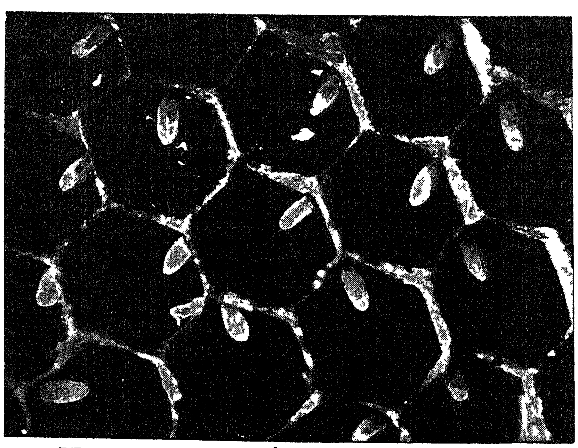
Of course, ants are not an undisguised blessing. The red ant, of the woods, is a menace to anyone who approaches its nest; the ordinary brown and yellow

ants work havoc with our food. The so-called "white ants", or termites, which have a marvelous organization and homes, are appallingly destructive to property. To realize the effect of their attacks upon woodwork, one has but to inspect the exhibits on this subject in any natural history museum. The voracity of ants is almost incredible, their powers of discovering food extraordinary One observer stored for a night half a dozen caterpillars, with their food, in an old-fashioned wooden matchbox, and placed them in a closet twenty-five feet from the front door, beneath the step of which ants abounded. In the morning the box contained $1\frac{1}{4}$ caterpillars and a swarm of ants, which latter, the moment the box was opened, added insult to injury by carrying off in concert the last survivor and the fragment. Never until that night, so far as could be ascertained, had ants made their appearance in that part of the house.



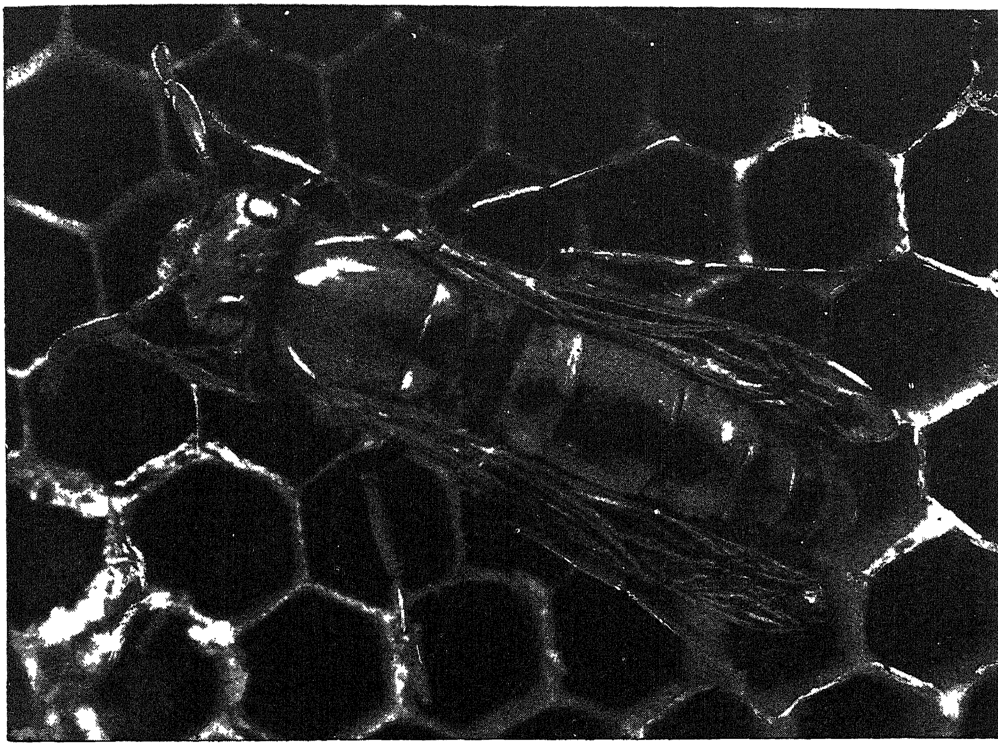
A QUEEN WASP HIBERNATING

A very late frost left one solitary plum as the harvest of an entire wall of fruit in a certain garden, and that plum grew in beauty and promise until the time of picking. The decision to harvest was left a day too late. From a tiny puncture in the plum, when the latter was plucked, emerged ant after ant; it was full of them, though the only external evidence was so small as to be imperceptible until the fruit was taken in the hand. In the spring, when strawberries are being grown under glass, the hotbeds swarm with ants, but when the fruit ripens in the grounds surrounding, not an ant is to be found under glass, though the fruit-trees outside will be found alive with them.

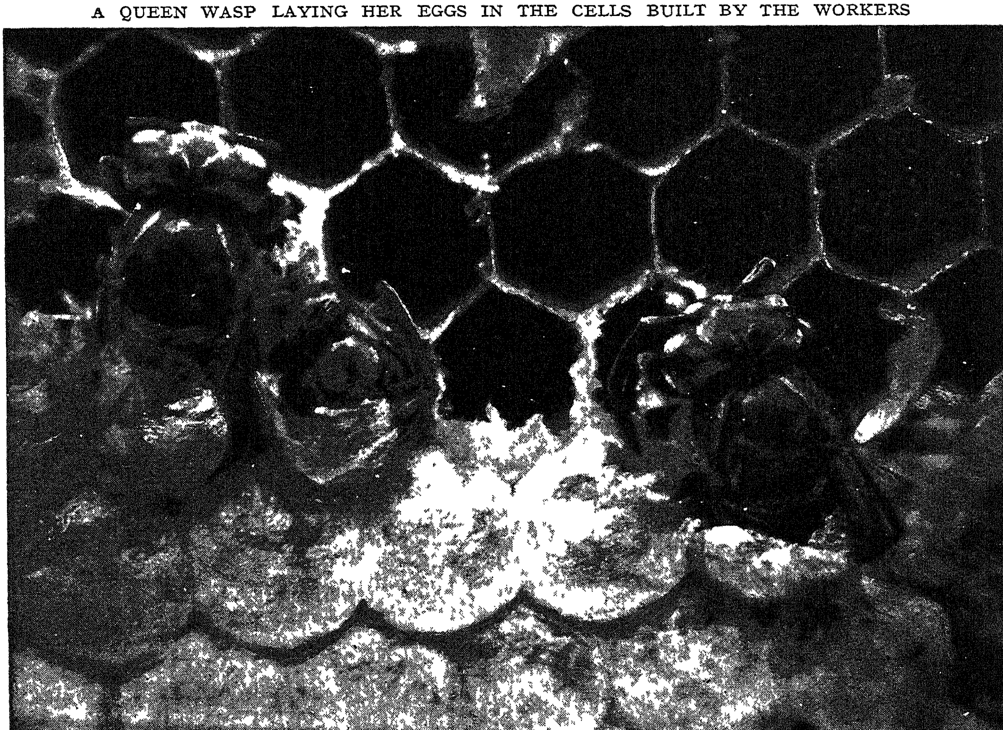


RECENTLY LAID WASP'S EGGS IN THEIR CELLS

Ants may be troublesome enough in our own land, but there are worse abroad, where they are alternately bane and blessing. One such is the saüba, or parasol ant, which derives its second name from its carrying its plunder in an upright position upon its head; and which is a terrible pest to South American cultivators, and especially to growers of coffee and oranges. These ants live in enormous colonies, whose external indications — far-reaching hillocks — convey no suggestion of the vast ramifications of the tunnels and chambers below ground. One observer gives us some notion by citing an experiment of which he was witness when a gardener in the botanic gardens at Para tried to exterminate these enemies of his work. With this object the man made fires over some of the main entrances to the colony, and by means of bellows blew the smoke of sulphur down the galleries Smoke was seen issuing from many unsuspected outlets, one being seventy yards from the point of entry. Still larger colonies have been traced. Where the saübas are in abundance they make cultivation practically hopeless, killing trees and shrubs by biting off the leaves. These leaves they use as ceilings for their underground dwellings, but some they store in



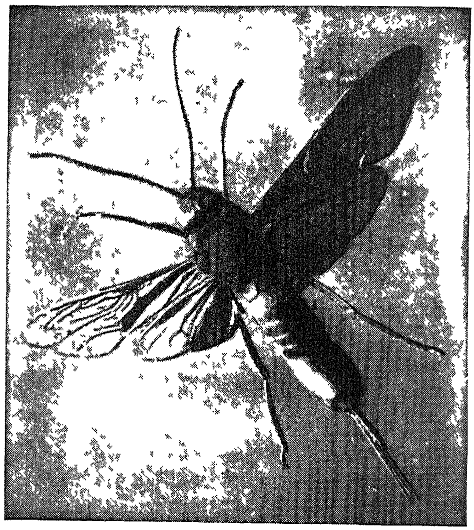
A QUEEN WASP LAYING HER EGGS IN THE CELLS BUILT BY THE WORKERS



YOUNG WASPS EMERGING FROM THEIR CELLS THROUGH THE SILKEN COVERINGS

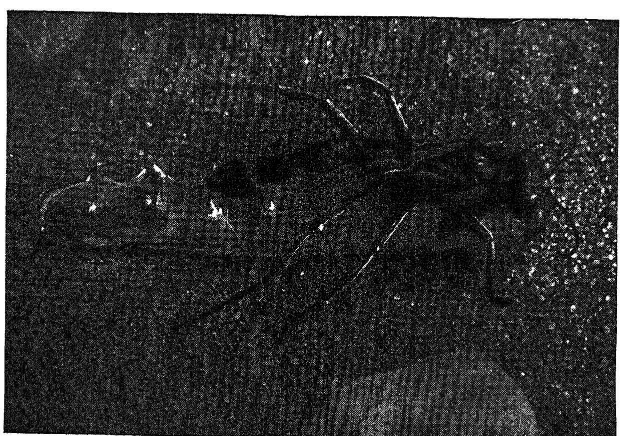
order that they may be able to eat the fungus which develops upon it. They enter habitations at night and devour food. It is to these ants that the redoubtable "soldier" ants belong — giants armed with terrific jaws. They accompany the ordinary workers when they go forth foraging, and do battle with any form of enemy, ant or other, which may threaten either the supplies or their bearers.

Another pestilent ant is the fire-ant (*Myrmica sævissima*), which becomes absolutely master of the situation in certain parts of tropical South America. It is in such numbers as to be invincible. These ants have their cities under entire villages, and at their most active season drive away the human population. They enter the houses, and dispute every mouthful of food with the rightful occupants, and devour linen for the sake of the starch that it contains. "All eatables have to be suspended in baskets from the rafters, and the cords well soaked with copaüba balsam, which is the only known means of preventing them from climbing. They seem to attack persons out of sheer malice. If we stood for a few moments in the street, even at a distance from their nests, we were sure to be overrun and severely punished, for the moment an ant touched the flesh he secured himself with his jaws, doubled in his tail and stung with all his might. When we were seated on chairs in the evenings, we had stools to support our feet, the legs of which were well anointed with the balsam." So were the cords of the sleeping-hammocks.



THE GIANT-TAILED WASP
This insect belongs to the wood-borer group of the Hymenoptera, and the tail is an ovipositor, not a sting

Still more formidable are the ecitons of tropical South America, and the driver-ants of tropical Africa. Although not structurally alike, they are similar in habit They march in irresistible numbers, and devour every animate thing in their track. They enter houses and clear up every scrap of living matter, from beetles and birds to spiders and scorpions. Nothing can withstand their enormous numbers, their powerful jaws and poison-charged stings; yet it is related that when not on the war-path they may be seen stretched at full length, extending their legs to be brushed and washed between the jaws and tongue of comrades, who finish the toilet operations by giving the antennæ a friendly wipe.



A SOLITARY DIGGER-WASP CARRYING OFF ITS CATERPILLAR PREY

Then there are the slave-making ants, which raid neighboring colonies, kill the adults and carry off the pupæ to rear them alive in their own nests, where the slaves in time become masters, doing all the foraging and fighting, feeding and cleaning their lords, who in time are dependent wholly upon their minions for all the necessities of life.

One other curious ant we must note — the honey-pot ant (*Myrmecocystus mexi-*

canus), which is simply an animated storage depot for honey. The abdomen becomes enormously distended with its contents, and such insects, sometimes too full to walk, remain in the cells of the colony to receive and conserve the honey brought in by workers, and finally to redistribute the store when the calls of hunger necessitate a demand upon the treasure A curious fact noted in connection with these ants is that when a honey-pot dies, the workers do not eat the honey which it contains — the body is nipped in two, and carried out of the nest and buried

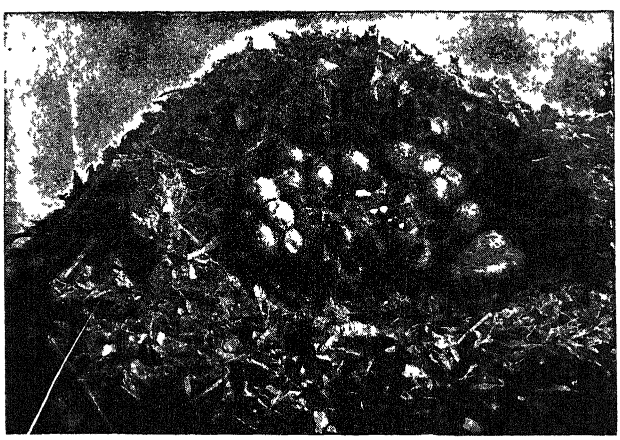
That ants store grain, or rather seed, is a well-established fact. They exhibit great skill in preventing it from germinating, by shifting it from place to place to prevent its being stimulated by heat or moisture, and, in case of failure in this direction, by nipping off the radicle of the sprouting seed. But success is not gained in 100 per cent of cases of this sort Excessive moisture may prove too much for the efforts of the husbandmen, and they are in that case compelled to carry out their useless grain. Thrown away some little distance from the nest, the germinating seed takes root, and this led to the belief, long accepted, that the ant actually sows and cultivates its crop. Of course, this is a wrong inference, based upon insufficient observation. There seems no doubt, however, that a fungus-eating ant (*Atta sexdens*) deliberately plants her crop, taking her fungus mycelium, tearing up a portion, saturating it with a drop of fecal fluid and carefully replanting it. The process is clear enough Whether the motive has been correctly estimated is, of course, not so easy to determine


THE NEST OF THE TREE-WASP

The beginning of a community of social wasps is not greatly different from that of the home founded by the solitary queen-ant There comes a time in every autumn when only comparatively few wasps are alive in the land The queens alone survive the winter The queen goes forth late in the summer for her nuptial flight, and meets the male Following this event, the queen seeks seclusion and shelter for the winter The choice of shelter is not invariably suggestive of high intelligence There is an attic in the home of one entomologist to which queen-wasps resort in winter How they get in is a mystery ; there is no window, and the only visible access is by way of a trapdoor which is not open to wasps. There must be some opening in the roof known to wasps alone. Year after year queen-wasps repair to that cold and cheerless attic. The singular thing is that at the lowest point of the sloping ceiling there is an opening into another attic room where a tank containing 150 gallons of hot water preserves a pleasant temperature, yet never a wasp has been observed there. Only in this one mysterious chamber are they to be found, cold and inert Needless to say, the queens of that apartment are not permitted to add to the wasp population, of some threescore discovered there last winter, not one escaped.

Wiser wasps find safer shelter ; and when the tide of life rises in the spring the queen

seeks a place for a nest — it may be under a roof, or in a bank, or some sunny grass-plot by the wayside. There she rapidly constructs a series of cells of paper-like structure, formed from woody fibers and other vegetable matter. She deposits in each cell an egg. When the larvæ hatch, the queen feeds them with the nectar of flowers and the juices of fruits until the time arrives for the larvæ to assume the pupa form, when they close their cells, undergo their metamorphosis, and emerge neuter worker-wasps. The workers assist the founder of the colony in making more cells, and in feeding the larvæ. Tier after tier of cells is made, and an egg hatched from each. Towards the end of the summer young queens, and after that the males, appear. The earlier generations have all been neuters or undeveloped females. Some of these, however, are capable of laying eggs, which, apparently unfertilized, may develop into males. The young queens and the young males finally leave the nest, never to return. The workers which remain destroy the larvæ left in the nest; then themselves await death. So much for the life-cycle of the social wasp, which, although it eats great numbers of insects, is so destructive of fruit and so venomous an enemy of human beings as to be almost a nuisance. The "hornet" is our largest wasp, and its sting is the most formidable in a formidable array of stings possessed by this undesirable family of insects.


THE NEST OF A HUMBLE-BEE, OPENED TO SHOW COCOONS

Wonderful ingenuity is shown in the construction of nests by various wasps, and it is a fact that these insects were the world's first papermakers. But not all form nests of this material; some of the solitary wasps make their habitations of sand, clay or mud — quite efficient dwellings, though less admirable æsthetically than the beautiful structure fashioned by the wood-wasp, *Vespa*. In the group to which this wasp belongs we find a singular method of furnishing a larder for the young. There being no workers, the parent has to provide food to which the larvæ upon hatching can help themselves This purpose is effected by the capture of various caterpillars, spiders and other insects. With terrible ingenuity the mother wasp leaves these alive, but paralyzed, in the nest. She stings them in a vital part, and the wretched victims remain motionless, but living, to await the attack of the larvæ's powerful jaws. It seems a hideous transaction, but it is believed that the living prey suffer no pain.

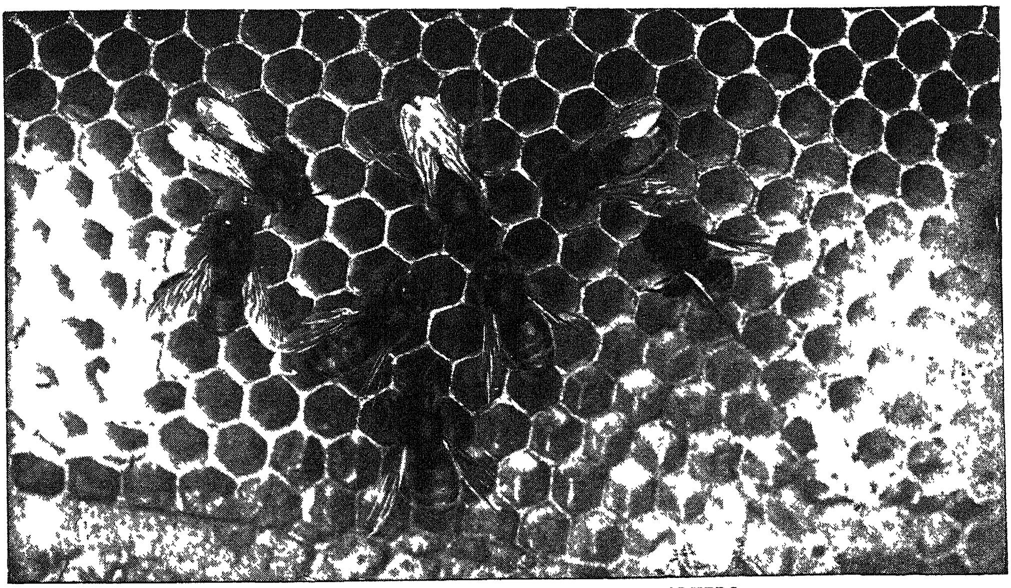
Other remarkable members of the hymenopterous order include wasp-like forms of similar habits, such as the tailed wasps, which, with powerful ovipositor drill, bore nurseries for their eggs in the trunks of trees; the egg-wasps, which are parasitic upon the eggs of insects and spiders; the gall-wasps and the ichneumon wasps; the sphex, which preys in the main upon members of the grasshopper tribe; and the pompilus, which does not hesitate to attack even such large spiders as the mygale, or bird-eating spider.

Finally, in the bees we have representatives of the order in which many naturalists find chief delight. Here, as in the ants, are three forms — the queens, the males and the workers or neuters. But the bees, unlike the ants, will have only one queen in a community. They seem to have solved the sex problem. The queen-mother knows what will result from the eggs that she deposits. She chooses a larger cell than the ordinary ones for the

egg from which a queen is to be produced, and the workers reserve a special regal diet for such larva. But should circumstances arise necessitating the conversion of an ordinary worker-grub into a queen, the change can be effected within a given time of the production of the egg. They need but to alter the diet of the grub from plain fare to royal, and, lo! the intended Cinderella is born a princess!

We may briefly trace the life story of a bee community from the point at which a fertilized queen leads forth a swarm from the hive to found a new settlement. Before taking their departure the bees gorge themselves with honey, in order that they may be sustained upon the way, and that their new home may not lack a larder. In a modern hive they would find foundation-cells already prepared for their reception, and would consequently have less labor. The process is more astonishing in one of the old hives, into which they are dropped or encouraged to enter. Where the queen goes they will go — to death if need be. She is the center, as she is the cause, of every swarm that we see, and she and they can be safely handled when gorged with honey, as they are for such a flight.

Within the hive is a great, black void, vast, in comparison with the size of the bee, as the most titanic cavern to a man. Here a home has to be built. Their only tools and materials are contained within their own organisms. They suspend themselves, one clinging to another, in the form of a curtain, from the roof of the hive, nearly to its base. Hour after hour they hang thus while secreting wax for the cells. This wax makes its appearance from glands beneath the edges of the segments of the body, and is rubbed off with the legs. In the meantime the entire hive has been cleansed by the remainder of the bees. The foundation-stone of the cells is laid at the apex of the hive. Wax, kneaded and rendered plastic, is brought up by bee after bee, is received, molded and fixed by a succession of architects, and a series of walls, each composed of six-sided cells, slowly grows downwards. As soon as a number of cells are ready, the queen, attended by a retinue of maids-of-honor, goes from cell to cell, depositing an egg in each. There is a frantic competition at the outset between the queen and the workers, for she is anxious to lay eggs at a greater rate than they can build receptacles while at the same time providing cells also for the storage of food. But the work goes on day and night, the queen, caressed and fed by her maids, proceeding from cell to



THE QUEEN BEE BEING FED BY THE WORKERS

cell and laying the foundations of the new community. Unerringly she places each egg in the appropriate cell, the drones' cells being larger than those of the workers.

Before she has nearly completed her task the eggs first laid begin to hatch. The egg is a bluish-white little speck, attached for the first three or four days to the bottom of the cell. At the end of that time the minute grub emerges, to float in food supplied in readiness by the workers When its head reaches the top of the cell, the nurses feed it — a treatment in response to which the larva waxes strong and

A DIVIDED SWARM OF BEES

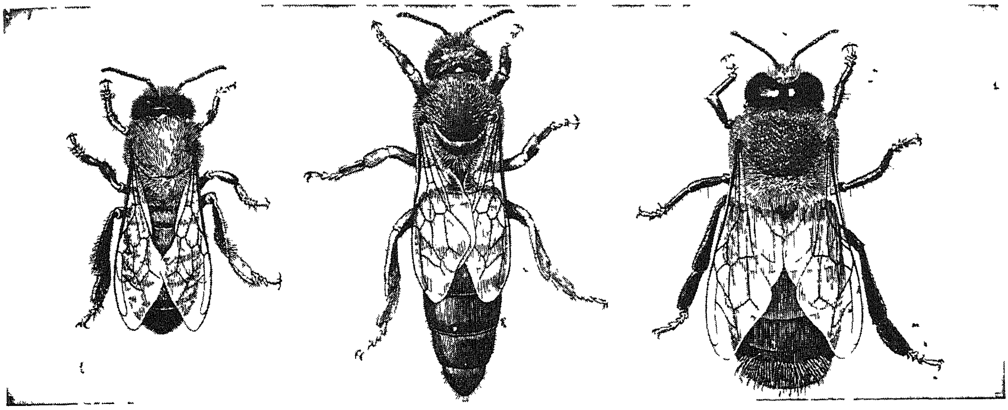
fat. Food is coming in all day long from the workers, which, flitting from flower to flower, collect nectar and pollen. The honey and the pollen, or bee-bread, are separately stored, and there is a grading of the pollen The grubs which receive the most nutritious food become queens — so few are favored.

It is still a much disputed point as to whether males result from the less nutritious food, but it is fully established that males predominate in the broods of hives poorly furnished with food, or where the queen is old and weak.

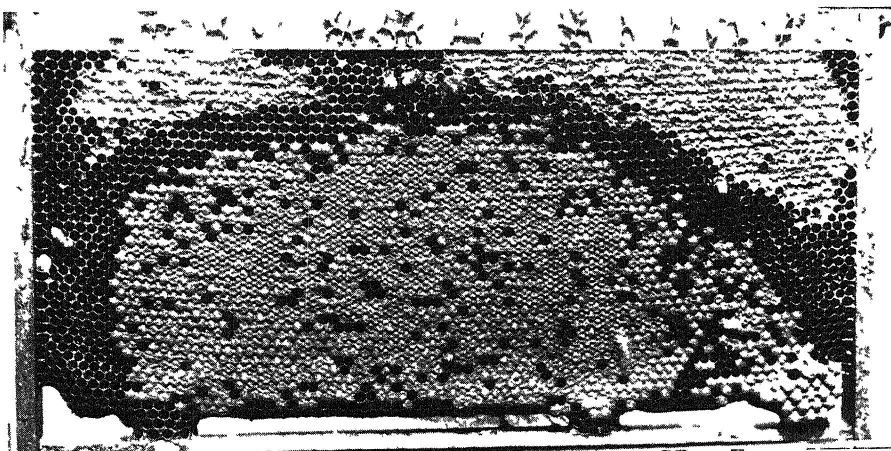
The grub, by whatever diet sustained, retires into its cell at the appointed time, and its cradle is sealed with wax by the workers. Within the cell the larva spins itself a robe of silk, and during the next nine or ten days effects the great change from pupa to adult. It gnaws its way out of its prison-cradle, and, after gaining strength, joins the workers in their task of scavenging or engineering, in the cooling and ventilating of the hive, a design effected by relays of bees vigorously fanning with their wings, and so maintaining a continual current of air. But if the young hopeful should prove to be a royal princess, the case is altered — she may not appear with such little ceremony Princesses may not emerge while the old queen is in possession, or she will slay them We have by this time, perhaps, got ten thousand eggs in the cells, and, it may be, twice as many larvæ, and a proportion of workers, and there will be seven or eight princesses The colony is therefore well established; so the queen must lead forth an army to begin afresh; she has thousands of additional eggs to lay She goes before the princesses make their appearance As soon as she hears their murmur within the cell she is filled with fury, for queen cannot tolerate queen, nor even princess She will, if permitted, approach the cell, and, with a thrust of her sting, kill the young life within it But here the workers, ordinarily so complaisant, interfere to prevent her; they are wiser than their mother and ruler. Foiled, she leads forth another swarm, and later a princess emerges from a royal cell, to be attended by the remnant of workers remaining. She takes her nuptial flight and returns to the hive, where, in due course, she will head a swarm to found a colony of her own.

Should two queens meet in a hive, a fight to the death results, but a wonderful provision of instinct, if such it be, prevents their simultaneously taking advantage of the opportunity to strike a blow when to do so would mean the death of both and a queenless hive. From such a posture both withdraw, to renew the fight upon such terms as shall insure the sur-

THE BUSY BEE AND ITS HANDIWORK



WORKER, QUEEN AND DRONE



Frame showing center well filled with brood in worker cells and a few drone cells at lower edge. Upper corners have sealed honey.

Photos Bureau of Entomology, U. S. Department of Agriculture

FRAME OF BROOD COVERED WITH BEES

vival of one. Towards the end of the summer, when it is undesirable that more swarms shall leave, the newest queen goes round to such cells as contain princesses, quietly puts each occupant to death, then settles down to her domestic duties in peace.

The importance of bees to mankind can hardly be overestimated. Their value to the country is infinitely greater than can be reflected in returns from the sale of honey. Bees mean abundance of fruit in orchards which would be otherwise sterile or practically worthless. Fruit-growers are advised by the Department of Agriculture to keep bees on their farms. The reason is obvious. From an ordinary stock of bees there are from 10,000 to 15,000 flying from blossom to blossom from early morning till evening. The result of cross-fertilization by bees is to produce greatly enhanced yields of fruit, and better and larger fruit at that. A fruit-grower in California had under cultivation forty acres of peach-trees. Being dissatisfied with the yield, he decided to cut down the trees and plant others, which he hoped would be better bearers. By the advice of an entomologist, who had noticed that there were no bees upon the fruit blossoms, he purchased two colonies of bees. The beneficial results were evident the same year, for there was at once a fair yield of fruit. So satisfied was he with the experiment that the owner enlarged his stock of bees in the following year, with the result that his trees were laden with excellent fruit.

The breeding of improved stocks of bees is now a well-organized industry, and Japan has profited by the calling, having introduced a number of fertile queens of approved lineage to take the place of her improvident own. The native Japanese bee is a sluggard, taking no thought for the morrow, but living pretty much on the terms of the wasp. The result was that not a tithe of Japanese fruit-trees were cross-fertilized, and not a tithe bore good pears or apples. Queen-bees have been taken to Japan within recent years, and the results are said to be excellent.

Photo Bureau of Entomology, U. S. Department of Agriculture

FINDING THE QUEEN

THE PERIODICAL CICADA

THIS STRANGE INSECT (often miscalled locust), which spends most of its life—13 years in the South, 17 years in the North—sucking at the roots of a tree or a shrub, regularly makes its appearance in enormous numbers.

Once above ground the life of the periodical cicada is relatively short. The winged adult lives for about a month—usually June—in the sunlight and fresh air. It announces itself by an earsplitting and never-ceasing uproar—the composite love song of the millions of males. This chorus ends only when the brood dies.

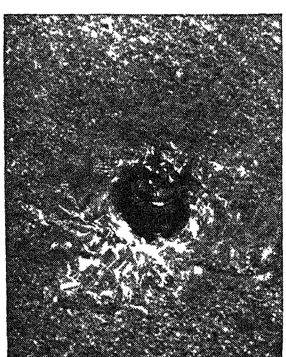
The din is produced by the vibration of two tough little drums of cartilage beneath the wings of the male cicada. The female is mute. The egg slits she makes in trees, shrubs, and plants constitute a sort of general pruning, not especially injurious to large forest trees, but hard on fruit trees and disastrous to young trees and nursery stock.

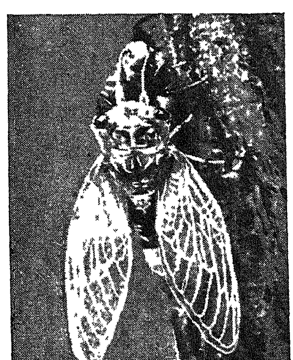
Startling features of periodical cicada outbreaks, one of which occurs every year in some part of the country, are the suddenness with which the insects appear and the enormous numbers that congregate in one area. Overnight the ground is riddled with millions of holes through which the nymphs emerged.

The adult emerges from the nymphal shell as a small, bizarre-looking creature, milky white, with red eyes. Its body soon hardens and turns black and its four nearly transparent wings unfold. The legs and margins of the principal veins of the wings are bright orange. Near the outer end of the front wing is a very distinct black "W," produced by deeper pigmentation.

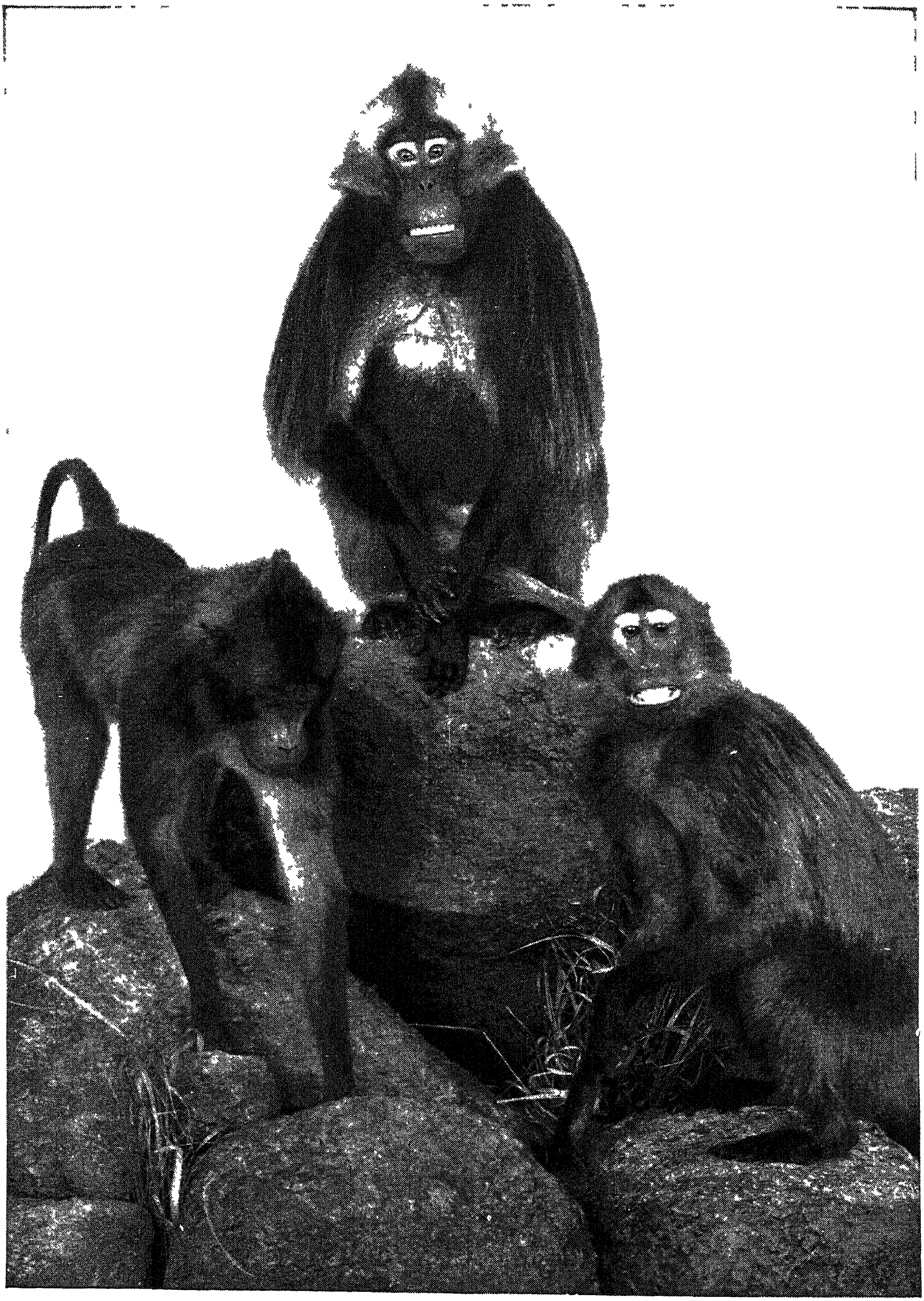
Early in June the adults start to die—first the males, then the females—littering the ground with wings and dismembered bodies. Innumerable larvae, hatching from the eggs, fall to the ground, burrow in, attach their mouths to a nourishing root, and wait for another 13 or 17 years to roll round.

The cicada is not dangerous to human beings. With its long sucking beak, it probably could sting a person, but, as a matter of fact, it never attacks anybody. On the contrary, it makes no effort to defend itself, or even to run away, when people pick it up or when birds feed on it. Consequently, the species has suffered heavy losses. Some broods, entomologists believe, have been entirely wiped out through weakening, as a result of the destruction of the forests, followed by the attack of birds.





THE LARVA OF AN AMERICAN CICADA LEAVES ITS UNDERGROUND HOME AND GROWS INTO A WINGED INSECT



Courtesy of Field Museum of Natural History.

GELADA BABOONS.

ZOOLOGICAL DEVELOPMENTS

by
JOHN T. NICHOLS
Curator of Recent Fishes, Department of Ichthyology, American Museum of Natural History

NOW AND THEN the advance of science in diverse directions raises the general level of knowledge to a point where some aspect of underlying principles comes into clearer view. In a discussion of "the migrations of animals from sea to land," published by the Duke University Press, A. S. Pearse calls attention to and emphasizes matters bearing on the forms of animal life which today have become rather obvious, and which may be more important than we now realize. There seems to be no doubt that most groups of animals had their origin in the ocean and gradually invaded fresh-water and land habitats, adapting themselves to new environments as they went.

At present "only one-fifth of the species of animals on the earth are aquatic. Though conditions of life on land are in some respects severe, they appear to have been, and are today, favorabie for the formation of new species Animals which have made the struggle up the long trail from marine and freshwater habitats and stand today on dry land are the dominant ones of the earth. They are the successful. What is success? Has the struggle been justified?

"Success is continual improvement. It is the result of competition for a place to live. There are of course various degrees of success. The mere fact that an animal is alive is a certification that it is to some degree successful. Among land animals, ants exceed all other types combined in individuals. They are successful and dominant among those which have attained land because they are progressive yet generalized. Ants are active, keen of sense, modern, and so progressive that they have built up a social organization that has long excited wonder and admiration among successful, dominant, and social vertebrates Yet ants have not generally limited their food to one or two peculiar substances, as the honey bee has, and they have not lost the thermal and aqueous stability that goes with close association with soil. A successful animal is both plastic and progressive. It must always live in the world as it is and to some extent do such living with greater efficiency than its rivals.

"Animals which struggle may look down with more or less contempt on those which are able, by lurking in the crevices or the slack waters of evolutionary currents, to find soft berths where they may exist without a struggle. Such degenerates pay the penalty exacted by the Gods of Biology. When they cease to struggle, they lose their abilities—they not only retrogress in power, but also lose appreciation. Every barnacle starts in life as a free-swimming nauplius with eyes and other sense organs. Barnacles which settle on rocks alongshore to enjoy life, where waves and tide perennially insure food and certain favorable conditions of life, lose their eyes, and thus to some degree their power to appreciate things outside themselves. Barnacles which go farther down the road which leads from struggle likewise start in life as apperceptive nauplei; but they attach themselves, not to sturdy rocks, but to other animals and lose all semblance to struggling crustaceans. As adults, they are rotund masses without legs or sense organs. They send rootlike absorptive organs into their unlucky hosts and thus steal food; their bodies become soft sacs which produce myriads of eggs. They have a certain success—they continue to live, but they are degraded, specialized, and limited. Land animals because they live in a changeful

environment are stimulated to be alert strugglers."

Ocean birds

Birds of the ocean, often spending the greater part of their lives at sea and nesting on remote islands, are less well known than song birds of the woods and fields. Despite their lack of gay plumage or sweet voices, however, many of them are exceedingly interesting, and it will be worth while to quote a few passages concerning their habits from a two-volume work by Robert Cushman Murphy of the American Museum of Natural History entitled 'Oceanic Birds of South America,' which forms an outstanding contribution to our knowledge of bird life.

Guanayes

The Guanay, a kind of cormorant, first in importance among the guano birds of Peru, has been called the most valuable bird in the world. "Picture to yourself the shining, rainless coast of Peru, washed by ocean waters to which storms are unknown, where the swells surge northward, from month to month and year to year, before winds that blow regularly from a southerly quarter. On such an ocean dark flocks of guanayes form rafts which can be spied miles away. Slowly the dense masses of birds press along the sea, gobbling up fish in their path, the hinder margins of the rafts continually rising into the air and pouring over the van in some such manner as the great flocks of passenger pigeons are said to have once rolled through open North American forests in which oak or beech mast lay thick upon the leafy floor.

"At other times, when the guanayes are moving toward distant feeding grounds, they travel not in broad flocks but rather as a solid river of birds, which streams in a sharply marked, unbroken column, close above the waves, until an amazed observer is actually wearied as a single formation takes four or five hours to pass a given point.

"Equally impressive are the homeward flights of these cormorants, after a day of gorging upon anchovies, when in late afternoon slender ribbons, wedges, and whiplashes of guanayes in single file twist and flutter, high in air, toward the rounded plateaus of white islands which gradually turn black as the packed areas of birds swell out from clustered nuclei toward the borders of the available standing room. . . .

"Given . . . a belt of cool ocean waters replete with small organisms . . . ., together with nesting sites upon islands which for climatic reasons could never become encumbered with vegetation, and the geographic stage was set for the northward emigration of the ancestors of the guanay. Furthermore, because of the normal superabundance of food, conditions seem to have been prearranged for the increase of the birds to numbers limited only by competition with other animals and by the amount of safe, insular space for reproduction. Although suitable islets are very numerous, the enormous food supply in the Humboldt Current is still out of all proportion to the area of the breeding places. This doubtless explains the excessively colonial nesting habit of the guanay, in which it surpasses all other birds, even the penguins, for in the middle of a bounteous sea there would be a constant tendency for the cormorant population to become more and more congested upon the islets. The doctrine of Malthus applies to birds as well as to men.

"These facts suggest that the geographic background does not tell the whole story. Evolution is, at least in part, the result of interaction between a living being and its surroundings. The guanay itself has had to undergo considerable modification in order to fit into a new environment, especially as regards the particular character of its food in the Humboldt Current. Several such adaptive changes are apparent, changes which have progressed so far that they now strongly differentiate the Peruvian species from its Antarctic cousins and from every other kind of cormorant in the world.

"For instance, the guanay, unlike any other cormorant, 'hawks' its food, that is, it hunts exclusively by sight and from the air, locating the fishes which it seeks before descending to the water to catch them. Most cormorants search for their prey individually, swimming alone or in loose groups at the surface, then plunging in what seem to be favorable places and conducting the hunt as well as the capture while they are submerged. For the most part, moreover, they subsist upon bottom-living species of fish, often diving down many fathoms in pursuit of single victims. But the guanay feeds altogether upon surface-swimming fishes, such as anchovies, young herrings, and the toothsome silversides which the Peruvians call *pejerreyes* ('kingfish'). Such forms travel in tremendous schools which are assailed *en masse* by proportionately large flocks of birds.

"The correlation between the numbers of the fishes and the extreme gregariousness of the cormorants results among the latter in a system of efficient co-operation which almost suggests certain customs of ants or other social insects. The vast flocks of guanayes which spend their nights upon the islands do not start hunting in a body when morning breaks. On the contrary, the birds first sally forth only in small scouting parties, which can be seen flying erratically above the ocean, usually keeping well in air, and frequently 'back pedaling' or hovering when they see the silvery glint of schooling fish or the ruffled appearance of the sea which indicates the presence of fish below. The dropping of the scouts to the surface, and the shallow dives which mark the beginning of an orgy, are the signals that cause the approach of such rivers of birds as have been described above. The cohort of guanayes then spreads out as a great fan over the unfortunate anchovies, which are likely to be no less harried from beneath by bonitos and sea-lions. Small wonder that the Peruvian fishermen, who are familiar with such sights, believe that the guanayes and the seals have a working understanding! However this may be, the gorging proceeds until both sea-lions and birds must cease long enough to allow their rapid digestions to fit them for another meal. From the crop and gullet of a dead guanay, the remains of no less than seventy-six anchovies, four to five inches in length, have been taken.

"Sometimes the guanayes pursue the fishes to the very beaches, so that a rare view of a one-sided fray may be enjoyed by a landsman. One morning during my sojourn at Independencia Bay shoals of silver-sides were packed in deep, glittering ranks close to the quiet shore, when a raft of guanayes, accompanied by a few pelicans and a horde of screaming gulls, drove the fishes before them against the shelving sand. Soon the water gleamed like flashing quicksilver, and in wild rioting the birds jammed and crowded each other until hundreds of them were pushed clear beyond the tideline by the scrambling mob behind."

The wandering albatross

Concerning the wandering albatross, the long narrow wings of which (a high "aspect ratio" being particularly efficient in its soaring flight) may measure 11½ feet from tip to tip, Dr. Murphy writes: "My first acquaintance with the species at the breeding grounds was at the Bay of Isles, on December 15, 1912, when many of them were already at the nests and others in the early stages of courtship. The albatrosses with nests were mostly squatting upon them, and when we approached they would rise up on straight legs and snap their bills with a single resonant clap. No eggs had yet appeared, but the colony was well sprinkled with young birds of the previous year, which were sitting here and there, between rather than on the nests. Some of these chicks were almost wholly covered with down, while others had lost the greater part of their gray fluffy covering and were in the blackish juvenal plumage, with white face and wing linings. The youngsters sat back on their heels, turned up their toes until it seemed

that they would surely topple over, snapped their bills in the manner of their parents, and also uttered curious gobblings and cacklings. . . .

"From December 15 until the middle of February I was privileged to see the courtship performances of the Wandering Albatross going on continuously, for as the early, older, and whiter albatrosses would settle down to the business of mating, nest-building, and incubation, the territory still empty would fill up with younger birds which had certainly not been anywhere near the breeding grounds until several weeks after the bulk of the mature albatrosses had arrived. Latecomers, many of them in the heavily blotched plumage which sailors know as the 'leopard' stage, continued to reach the Bay of Isles and to begin courtship at least as late as mid-February, or fully eight weeks after the appearance of the first albatross eggs. On February 13 I noted new batches of dark-plumaged birds of both sexes squealing, chattering, posing, quarreling, and mincing around one another with unfolded wings—all this going on among the nests of quietly incubating white birds which I had had under continuous observation since December. . . .

"From my own observations it seems clear that most of the early arrivals at the nesting ground are male birds, which claim and occupy individual territory in anticipation of the coming of mates. For some time, therefore, the early female albatrosses are outnumbered four or five to one. The males leave their squatting-posts to cluster about the first females, which are commonly besieged by from two to six, or even more, ardent yet orderly suitors. The males throw forward their breasts, stand upon their toes so that the metatarsal joint clears the ground, stretch out one or both wings, raise and spread the tail, gobble and squeal, and then touch bills with the female, which also responds in kind to most of the other gestures. Waite noted on islands south of New Zealand that drops of oil ooze out of the beak during the billing reaction, and concluded that a slight regurgitation accompanies the performance. The sounds produced by the syrinx are varied by percussion notes from the beak, which begin as choppy clips and end in rapid vibratory shivering. The booming, mechanical sound of this is concluded by a vocal shriek or groan from both participants.

"Although the object of each male is apparently to confine the attentions of the female exclusively to himself, there is considerable etiquette in the performance, for each in turn holds the center of the stage before the hard-pressed female. The rivals may be by no means idle during a spectacle which is primarily dual, and yet, to a certain extent, at least, they appear to stand by while one particular bird holds the center of the stage. At times they turn toward one another, expressing what might be assumed to be a low opinion of rivals in general, for their jargon certainly has an abusive sound. They also appear to threaten with snapping beaks, although I gained no evidence of actual combat between males until after mating had taken place. The female seems to distribute her attentions about equally among the suitors. At times the males least occupied at the moment walk away from the group for a short distance, with their heads swaying from side to side and hung almost to the ground. The attitude gives them a diabolical look, and it would be easy to imagine that dark and sinister thoughts were occupying their minds!"

Emperor penguins

The emperor penguin, largest species of those peculiar seal-like birds, incubates its egg on the ice in the Antarctic winter. "The courtship behavior of the Emperor Penguin is unknown, but the birds lay their single egg on sea-ice close to Antarctic shores about the end of June, and incubate it on their feet in the same manner as the King Penguins. The season of midwinter darkness is at least correlated with the greatest thick-

ness of the ice, which makes for the safety of creatures that choose so precarious a nursery. Since seawater is at the same time necessary as a source of food, the breeding stations also have a definite relation to permanent leads or other openings in the ice, and these are most likely to be maintained by tidal movement very close to coasts and glacier fronts.

"Below the wall of Ross Shelf ice, for example, there is commonly a wide crack in the sea-ice. Moreover, the prevailing southeasterly winds tend continually to broaden it by forcing the growing ice-fields northward into Ross Sea. On the anchored ice of a small bay, at the point where the barrier abuts against Ross Island, is the rookery of Emperor Penguins visited on various occasions by Wilson and his several associates. Here, it was believed, no bird would ever have to walk farther than a kilometer and a half or thereabouts without finding an opening through which it could enter the ocean in quest of food.

"Just how the penguins search out their prey at this season is a problem which has, perhaps, never been raised. Day or night above them is a continuous Stygian gloom, and surely no visible ray from even a clear firmament of stars can penetrate the frozen roof of the cold black water in which they forage. Eyes would seem of little use. Do the penguins merely feel for fish and squids and crustaceans? Or have they a sense of smell like that of a ground shark?

"From afar the metallic trumpeting of the brooding Emperors can be heard through the polar night. When approached, the birds with eggs attempt to shuffle out of the way, but, if they are hustled, they are likely to drop their burdens, and these are picked up, almost before they stop rolling, by eggless birds which act as though they had been waiting for no other opportunity.

"In different seasons Wilson estimated that from one in five to one in twelve, among the total population of the Cape Crozier colony, had an egg. At best only a small fraction of the birds breed during any one winter, and yet the unmated or barren individuals respond as warmly to the progeny of the rookery as do the actual procreators. All adults of both sexes not only share the active instinct for brooding, but all are also characterized by a patch of bare skin on the lower abdomen. Thus many old birds, rather than merely two parents, take turns in nursing each chick and egg, a custom which allows ample time for all to find open water, even under difficulties, and to obtain the great quantity of food that they must require. So irresistible, however, is the desire for mothering something, that eggs formerly frozen and long addled, dead chicks in the last stages of being worn to pieces, and even lumps of ice of convenient size, are tucked on to the feet and covered with the feathery muffs of numerous would-be fathers and mothers."

Migratory birds

Though the winter home of the chimney swift, perhaps in the forests of Amazonia, still remains a mystery, we are learning much concerning its movements in the United States. We read in *Bird-Banding* that from August to October 1936, approximately 28,000 swifts were trapped in chimneys in a considerable area centring about Auburn, Ala., where swifts congregate on their southward migration. Among them were birds originally banded as far north as Ontario and the Bay of Fundy, and at intermediate points in New York, Pennsylvania, Virginia and West Virginia, Tennessee and South Carolina. The recapture of the bird from the Bay of Fundy was 28 days after it had been banded, about 1,500 miles to the southwest.

Some day we may have a record from South America of a chimney swift carrying a band placed on it in our Eastern States. The chances of such a recovery are of course much greater in water birds. The Biological Survey already has records of a little blue heron from South Carolina in Venezuela; blue-winged teal from Quebec in British Guiana; a lesser

yellowlegs from Cape Cod at Sao Paulo, Brazil; a number of common terns from Maine, Massachusetts and New Jersey, in British Guiana, French Guiana, Venezuela and Brazil; a roseate tern from Massachusetts and least tern from Florida in British Guiana; a royal tern from South Carolina and two Caspian terns from the Great Lakes in Colombia; a Wilson's plover from South Carolina in British Guiana; a semipalmated sandpiper from Cape Cod in Venezuela.

Museum exhibits

Two of the most interesting zoological exhibits to be found anywhere in the world are housed in the American Museum of Natural History in New York City and the Field Museum of Natural History in Chicago One of the latest additions to the American Museum of Natural History is the new African Hall, which, when completed, will give a comprehensive picture of wild Africa, foremost game country of the world, and its larger mammals The gorilla, lion and buffalo are most impressive; the zebras, and the endless variety of size, form and color in members of the antelope family from the giraffe down, intrigue the imagination and delight the eye; a pack of the roving wild dog, *Lycaon pictus,* which hunts mostly at dawn or dusk or when the moon is full, gazing out across the plain, introduces a notable animal which most persons who have not been to Africa have never heard of.

We read in *Science* that a habitat group of gelada baboons from Ethiopia, a species of ape which has no counterpart elsewhere, has been placed on exhibition at the Field Museum of Natural History, Chicago, which is constantly adding to its collections. The group shows an old male, with the mantle of long flowing hair producing a decidedly leonine effect characteristic to geladas of his age, seated on a rocky prominence. Just below him are a female and a half-grown baboon, engaged in exploring crevices in the rock.

"The gelada baboon, according to Dr. Wilfred H. Osgood, curator of zoology and leader of the expedition which collected the specimens, is strictly a resident of Ethiopia, and is confined to the rock walled canyons and high mountain crests. Apparently it has occupied its present position in the country for a long time, perhaps almost as long as the volcanic mountains in which it lives. Its near relatives, which may have occupied other parts of Africa also, are now all extinct, and it is left alone on the Ethiopian highlands. Dr. Osgood writes:

'Africa is a land of baboons, and within that continent Ethiopia is headquarters for several of the most important species In eastern Ethiopia, mainly in the hot lowlands, are found the hamadryas baboons which extend into the Sudan and Arabia; and in other parts of the country are found also the dog-faced baboon, closely allied to forms found throughout Central Africa. The more exclusive geladas differ markedly from other baboons Although almost wholly terrestrial in habits, the gelada has certain peculiarities indicating a possible distant relationship to tree-living African monkeys. The gelada's legs are relatively slender and the tail fairly long On its breast is a peculiar shield-shaped naked patch of a florid pink color.

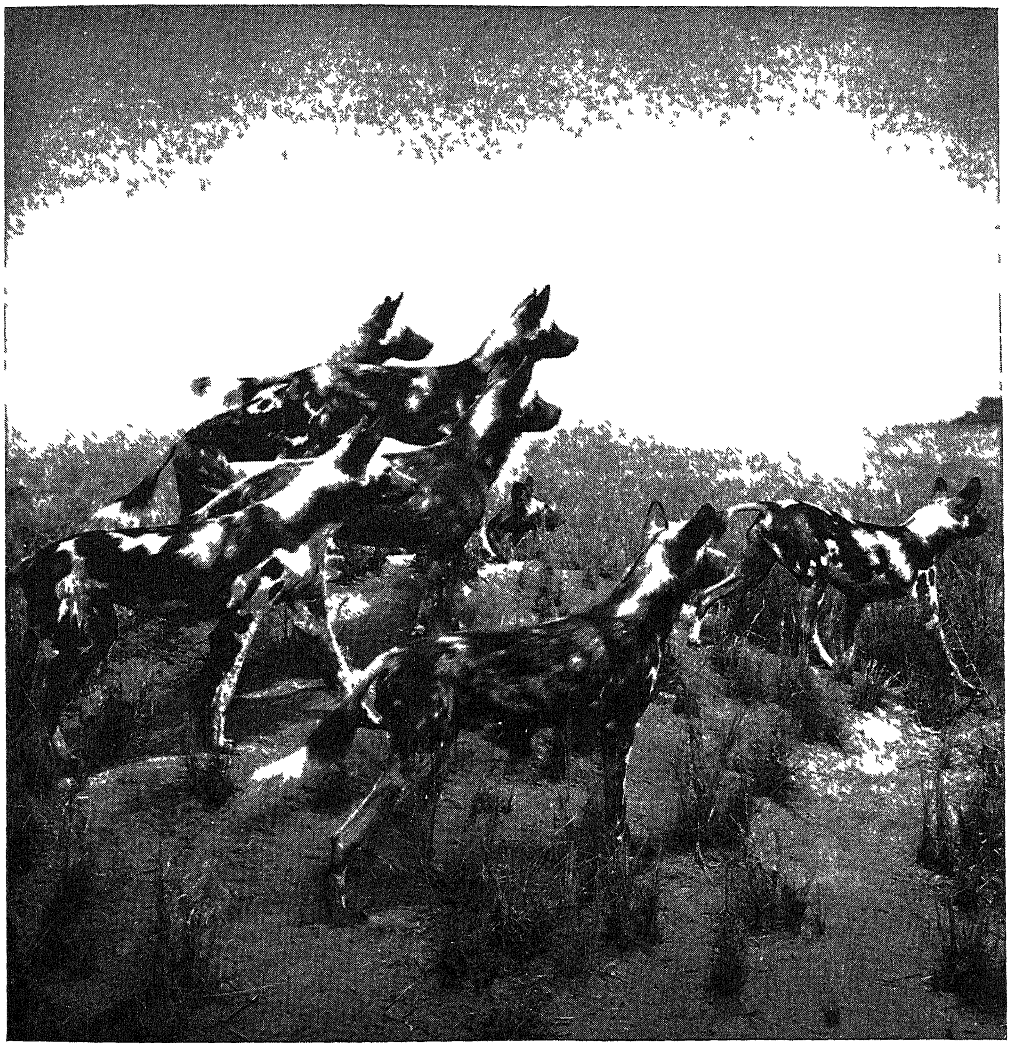
'The gelada rarely descends below an altitude of 6,000 feet. In the rocks and caves where it lives the temperature frequently drops to freezing. Like other baboons, it is gregarious. It is very agile and is credited with rolling boulders from a height to disconcert any animal which may be approaching.

'The hunting of geladas is extremely difficult, calling for much hard climbing, and many long shots. The baboons sighted on our expedition seemed always to perch on pinnacles from which, if killed, they would fall into such yawning depths below that retrieving them would be next to impossible. The help of the natives was invaluable in these places, for the ability of a barefooted Ethiopian to scale a cliff is second only to that of the baboons themselves.' "

The life-span of animals

We also learn from *Science* that "on May 14, 1931, the Philadelphia Zoological Garden received a thirty-five-year-old male chimpanzee, 'Jimmy,' who claimed distinction of being the oldest of his species in captivity and of being the father of the first chimpanzee born in captivity (Anumá). Old 'Jimmy' came with a reputation of being a 'tough customer,' up to which he lived for some time; then gradually he became quite manageable, and during the last months of his life he was gentle and friendly. . . .

". . . When observed in September (1935) 'Jimmy' was not the animal known in the literature. He was not a morose, unmanageable old male, with ugly disposition and outbursts of violent activity, but a quiet, obedient, rather slow in movement senile chimpanzee with small and apparently weak muscles, wrinkled skin, poor pelage, sprinkled with white hair and bald patches. His appetite and digestion were remarkably



Courtesy of American Museum of Natural History

Wild dog (Lycaon pictus) group in African Hall, American Museum of Natural History Animals by R H Rockwell, background by R Kane, group planned and directed by J L Clark

good." He died on November 28, an old man at 39, confirming the general belief that the life span of a chimpanzee is half that of a man.

The life-span of different animals is a matter of much popular and sometimes some scientific interest. In the great apes we may assume it bears a similar relation to the period of youth and growth that it does in man, but this is by no means always the case. From the University of Wisconsin there is a report of a female domestic rabbit which died in February, 1936, at the advanced age of ten years and three months.

The black widow spider and the alligator lizard

There has been much discussion of the poisonous black widow spider in the United States. It is the general belief that this undesirable creature is increasing in California, one of its centres of abundance, and strong circumstantial evidence has been brought forward that this increase is correlated with decrease of the alligator lizard, *Gerrhonotus multicarinatus*. Lizards in general it seems, will eat this spider, and the habitat of this particular lizard, which will also eat its egg sacs, is such that there would be frequent opportunity for it to do so. The decrease of the lizard is referable to human antagonism, clean methods of modern gardening, and the predatory skill of the domestic cat.

Hymenopterous insects

There seems no end to the complexity of reproductive adaptations in hymenopterous insects. Writing in *Science,* S. E. Flander says: "In certain species of parasitic Hymenoptera, particularly those belonging to the genus *Coccophagus,* the males develop only as parasites of hymenopterous larvae and the females only as parasites of homopterous nymphs or adults; *i.e.,* mealybugs or scale insects. The hymenopterous host, however, must be within a homopterous insect. This is a remarkable differentiation in the host relations of the sexes within a species.

"The production of males in a pure culture of a species having such a habit necessitates the destruction of immature females since they are the only hosts of the male present in the culture. The conditions under which the destruction of the females occurs vary with the species.

"Apparently in all the species the female is endoparasitic. The male, however, in some species, may be endoparasitic, in some ectoparasitic and in others alternately ectoparasitic and endoparasitic. The male exhibits marked differences in the structure of the respiratory system and other morphological characteristics.

"As in other species of Hymenoptera, the male develops from unfertilized eggs deposited by unmated females. These females either deposit their eggs directly on or in the immature hymenopterous host or they deposit them in the fluid media surrounding such hosts. In this fluid media the eggs remain unhatched until the hymenopterous host is in a suitable condition for attack."

The electric eel

One of the strangest of fishes is the electric eel, *Electrophorus electricus,* found in the rivers of South America, a slimy-skinned, blunt-headed, eel-like creature, actually more closely related to such unlike fresh-water fishes as carps and catfish than it is to the true eel. It has the power of liberating voluntary electric charges into the surrounding water, so controlled as to stun the small fishes swimming by, on which it feeds. The New York Aquarium has recently had a number of living electric eels in its collections, the longest over seven feet in length, and the nature of the in many ways mysterious electric discharge has been studied in its laboratories. It was soon found "that the current may be released from any part of the fish with equal intensity; that it is directional, having one polarity at the head and another at the tail; that it is of at least eighty volts value; that the fish can regulate the amount it discharges, and that it can be made to actuate any ordinary electrical circuit of the appropriate value.

LIVING MECHANISMS

by

THEODORE H. EATON, Jr., Ph.D.

Assistant in Biology, Cornell University

Certain parts of animals are remarkably similar to human inventions. The heart, with its valves, pipes and contracting chambers, is a living pump. The poison sac and hollow fang of a rattlesnake are a living hypodermic syringe. Any quadruped is a walking cantilever bridge, its long axis supported on pillars by means of numerous oblique muscles and tendons. Mechanical principles are involved in the life of every organism, in any stage of its development, whether egg, embryo or adult. This does not imply, however, that an animal is merely a machine, for machines neither build themselves nor produce others of their kind.

Is a living mechanism evidence of a plan? Is the human eye, for instance, a "marvel of design" or is it the result of a long series of "accidents"? Such time-honored questions are asked less and less frequently today. The past history of the heart as a pumping organ will show why.

In the little fish-like Lancelet, which resembles certain predecessors of fishes living about five hundred million years ago, the heart is a scarcely perceptible swelling in the main artery of the throat (*fig.* 1, a). It has no valves, no division into chambers, only one entrance and exit for the blood. But it contracts rhythmically and forces the blood slowly forward in the artery. When sharks and the first true fishes appeared on earth, some 350 or 400 million years ago, they were provided with a more effective pump, but it differed from the preceding one simply in having two chambers with a valve between (*fig.* 1, b). Blood was squeezed out of the foremost chamber into the artery, and then as the walls expanded more blood entered from the second chamber, to be sent forward at the next "beat." The valve was placed where it prevented a backward flow of blood, and thus the circulation kept going always in the same direction.

After fishes' hearts worked in this manner for another hundred million years a new alteration occurred in certain peculiar fishes that took to the land, breathed air and became four-legged. As the first terrestrial backboned animals these formed the class Amphibia, represented today by frogs, toads and salamanders. Since lungs, instead of gills, were the new instruments for supplying oxygen to the blood, they necessitated a corresponding change in the circulatory system. The heart became three-chambered (*fig.* 1, c). The original second chamber of the fish divided into two separate ones, each communicating with the one in front by a valved opening. The two behind, then, are the right and left auricles; they receive blood from the lungs and the rest of the body respectively. The one in front, which is large, muscular, and does most of the pumping, is the ventricle. It sends a part of its contents at each beat to the lungs for oxygenation, and a part to the body as a whole. There is, consequently, a good deal of confusion and mixing in the ventricle of blood which is oxygenated with blood which is not. Some of the impure blood runs around through the body a second time, or several times, and some of the pure blood goes again to the lungs. So, while a heart of this

kind made one necessary adjustment to breathing air in the lungs, it did not, for a long time, overcome the disadvantage of a single ventricle pumping blood to two different places.

Then, about two hundred million years ago, after these Amphibia gave way to the dominant class of reptiles, some among the latter became warm-blooded and acquired a four-chambered heart, by a complete division of the ventricle into two (*fig.* 1, d). Now the blood was pumped from the right ventricle through the aorta into the remaining systems of the body, without mixing the impure with that which had been oxygenated. The followers of these progressive reptiles are mammals, that is, all the warm-blooded animals with hair, and man.

But during the reptilian age some of the smaller dinosaurs also became warm-blooded and developed a four-chambered heart. This, although the same in principle as that of mammals, had a reverse arrangement of the ventricles. The right one pumped blood through the whole body, while the left sent its share to the lungs. These small dinosaurs simultaneously developed wings, the power of flight and a covering of feathers. They were the first birds. Among the present day reptiles the alligators and crocodiles, strangely enough,

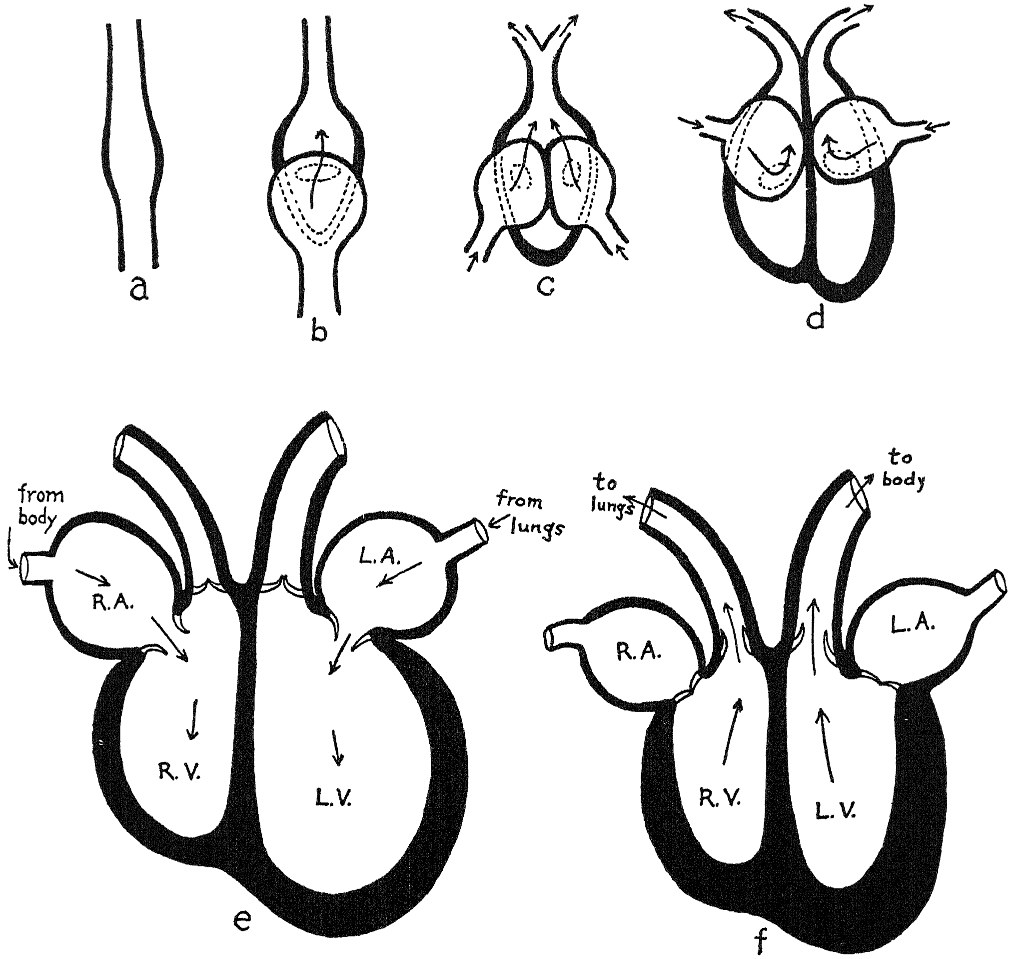


FIGURE I

are most like the archaic birds, for they have an almost completely divided ventricle and the temperature of their blood is partially controlled.

When we consider this slow addition to the heart, over a period of half a billion years, of new features any one of which did not greatly alter a previous condition, but came as an adjustment to vitally urgent influences, we no longer question the power of hereditary variations to produce a complex mechanism.

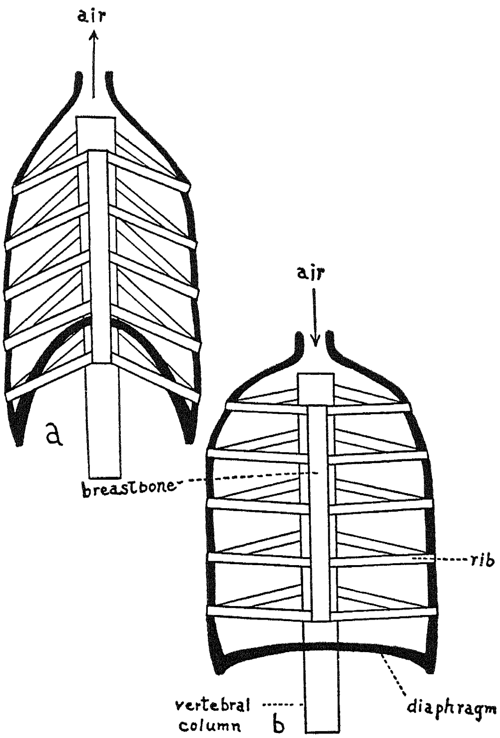


FIGURE 2

We may follow a similar course of gradual changes through a longer or shorter time in the perfecting of any adaptation, provided that enough stages are available for study.

There is probably no pump more complex than the four-chambered heart to be found in animals, but there are numerous simpler ones. The human ribs and their muscles, with the convex diaphragm beneath, make an efficient bellows (*fig.* 2). As the ribs lift up, hinging on the backbone, the diaphragm contracts to make a nearly level floor for the chest cavity. Air comes into the lungs to fill the partial vacuum. Then as the rib muscles and diaphragm relax the chest returns to a smaller capacity and expels part of the air. Ordinarily only a fraction of the air in the lungs is changed at each breath, and exhalation is not forcible but passive.

The mouth and gill breathing of a fish illustrates a two-way water pump (*fig.* 3). A pair of valves in the front

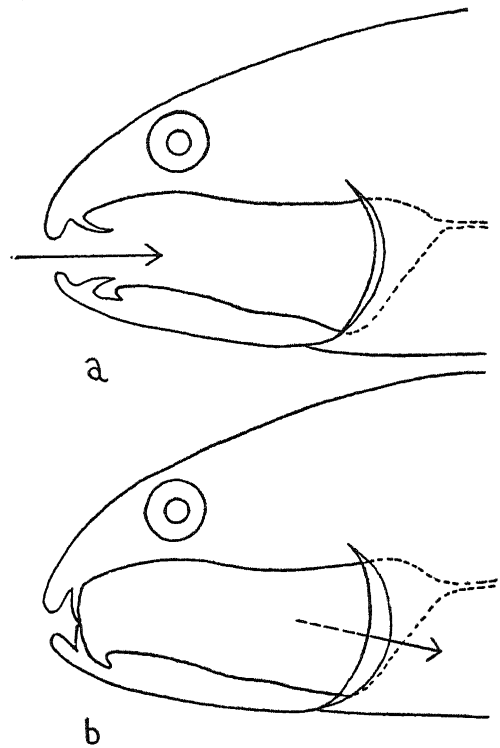


FIGURE 3

of the mouth open and close against the water pressure within. This allows a fish to pass a current intermittently through both gill-openings by merely contracting the walls of its mouth cavity, not even closing the mouth completely. Looking at a fish in an aquarium one may easily see the valves open and shut, alternately, without the opening and shutting of the gill slits.

Peristalsis, the pump action of any tube in which waves of contraction pass along and force the contents of the tube

with them, is illustrated by the intestine (*fig.* 4). The same contractions, when applied to a surrounding medium, pro-

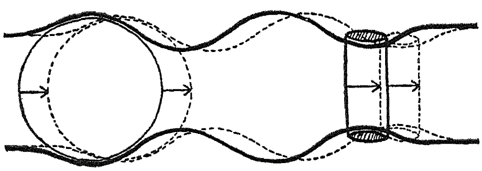


FIGURE 4

duce forward movement of the tube itself. This is the behavior of an earthworm in the ground. The diagram shows a large ball within and a small ring outside a peristaltic tube. The ball is pushed by the waves of contraction, and the ring is carried along by the resulting expansions.

Of the countless kinds of sucking apparatus, that of a squid is typical (*fig.* 5). Each tentacle of these creatures carries

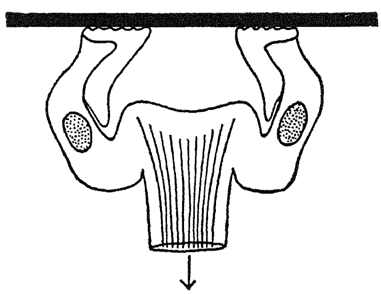


FIGURE 5

hundreds of small sucking cups, which fasten upon any surface that they touch. When the rim of a cup meets a solid object a muscle in the stem of the cup pulls the bottom down and reduces the water pressure inside. The pressure of the water outside is then greater and holds the cup against the surface. It can only be loosened by relaxing the muscular plug at the bottom.

The two following mechanisms are adjustable floats or buoyancy tanks. The simpler of the two occurs in the adults of the common newt (*fig.* 6). The lungs, developing only at maturity, preserve the animal's equilibrium while it swims or floats. A peculiar rod of cartilage lies in the abdominal wall, pivoting up and down on the pelvic bone. This rod can be pushed up against the rear end of the lungs, pressing the air that they contain forward. The newt's head then floats up, so that it can rest without effort at the surface, looking out. This is a favorite attitude.

The air bladder of certain fishes, the carp, minnows, suckers, catfishes and others, keeps the fish balanced against the changing pressures of deep and shallow water. In the carp the air bladder is double (*fig.* 7, a). The two chambers have somewhat contractile walls and a narrow opening between, which can be closed by a muscle. The contraction of either chamber forces air into the other, thereby altering the lengthwise balance of the fish. A small tube runs down from the posterior sac to the gullet, so that occasionally air may be expelled forcibly. The primary function of the air bladder, however, is shown by comparing a fish with the toy Cartesian Diver (*fig.* 7, b). This is a hollow glass doll in a jar of water. The amount of

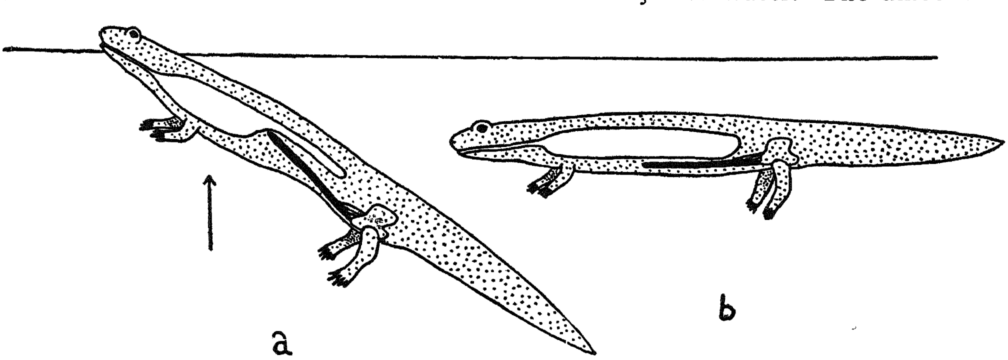


FIGURE 6

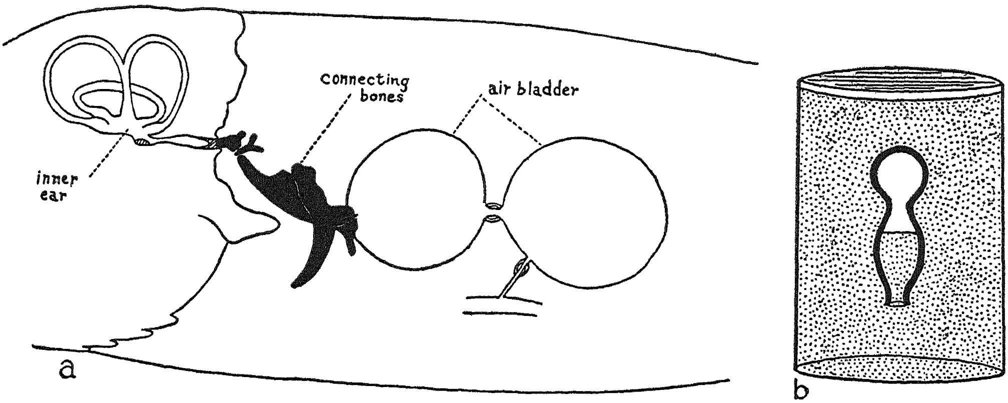


FIGURE 7

air in the doll is exactly enough to keep it suspended in the water without rising or sinking. There is an opening at the bottom through which the water enters part way to meet the air directly. Now the glass doll by itself is heavier than the volume of water it displaces. Without the air it would sink to the bottom. Similarly a fish, with its bones and scales, is heavier than the volume of water it displaces, and the buoyancy of the air in the bladder exactly compensates for this excess weight. The jar containing the Cartesian Diver has a flexible but watertight cover. When the cover is pushed down it increases the pressure of the water on the diver, reducing the volume of air that the doll contains. Therefore the doll sinks, for its air no longer displaces enough water to make up for the weight of the glass. Similarly, if the fish swims into deeper water, the increased pressure acting through the body walls reduces the volume of air in the bladder, and the fish is then relatively heavier than the water it displaces. The reverse, of course, happens to both the diver and the fish when pressure is reduced. The diver cannot adjust itself to the new conditions, but the fish can increase or decrease the amount of air in its bladder to relieve the greater or lessor pressure of the waters. It thus remains in equilibrium at different depths.

Extending forward from the air bladder to the cavity of the inner ear is a series of four small bones. Any change in the size of the air bladder, resulting from a change of pressure, is relayed to the cavity of the ear. There is an automatic nervous reaction which causes more gas to be secreted into the bladder if the contact with the ear is too light, or causes some of the gas to be absorbed back into the blood if the bones press too heavily. The fish, of course, is unconscious of this whole apparatus, on which it depends as much as we do upon our sense of balance.

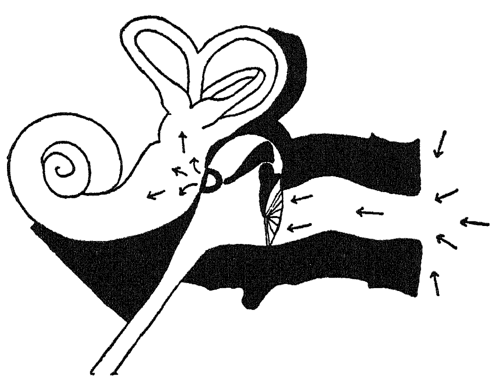


FIGURE 8

A large class of animal mechanisms transmits vibrations. The most familiar of these is the chain of three small bones extending from the ear drum to the sensory cavity of the ear in man and mammals (*fig.* 8). The first one, the incus (anvil), receives sound vibrations from the ear drum and transmits them to the malleus (hammer) and stapes

(stirrup). The stapes makes contact with the canals of the inner ear, in fact forming part of the wall of the same cavity, and sends the vibrations through the watery liquid within to certain clusters of microscopic hairs. These respond to the sound-waves by sending nervous impulses to the brain, where hearing takes place, according to the intensity and pitch of the vibrations.

A salamander or newt has no external ear whatever, yet it can, when adult, receive sound-waves from outside through a curious connection of the forelegs to the inner ear cavity (*fig.* 9). This cavity is close inside the rear wall of the skull on each side, and at the point where the wall is thinnest there are two minute

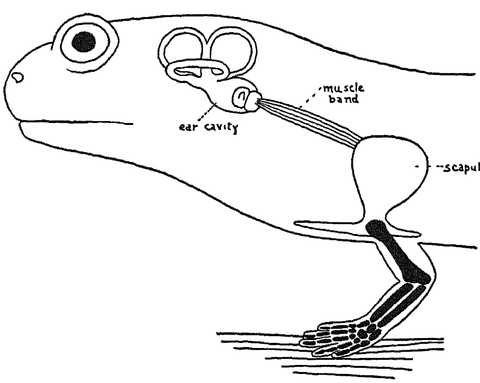


FIGURE 9

plates of bone mounted in a flexible membrane. One of these bones connects directly with the shoulder blade or scapula by means of a slender muscle band. The scapula forms part of the base to which the limb bones are attached, and vibrations consequently travel from the ground up the foreleg, into the scapula and across to the ear. The swimming salamanders have no such muscle band to the ear, for they do not walk on the ground.

Another kind of vibrating instrument produces sound-waves instead of receiving them. The human larynx is one of these. The windpipe entrance resembles a pair of sliding doors, which may be drawn close together or held apart (*fig.* 10). Between them all the

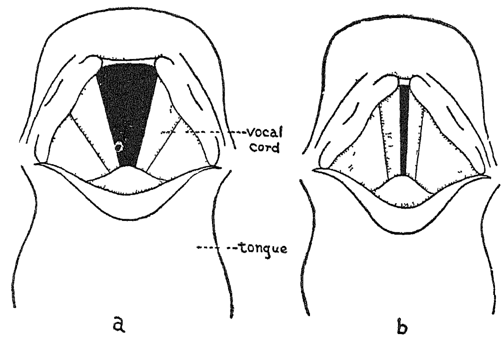


FIGURE 10

air to and from the lungs must go. The edges of the doors are the "vocal cords". Their pitch, or frequency of vibration, depends on how closely and tightly they are held. The narrower the slit between, the faster the air rushes through, and the higher the pitch of voice. A man's larynx, the "Adam's apple," is larger than that of a woman. The vocal cords are correspondingly longer, vibrate more slowly, and give a lower tone to his voice. Resonance of the air in the mouth and nasal cavities produces the variable qualities of speech.

The song-box or syrinx of a bird is entirely different from the larynx of a mammal. Instead of being at the entrance to the trachea, in the throat, it lies inside the chest cavity where the trachea divides into two bronchial tubes to the lungs (*fig.* 11). The syrinx varies enormously among birds, just as do the sounds it produces, but it is relatively simple in the domestic fowl. The wall of the trachea thins out at four places, making four tight membranes. Two of these are

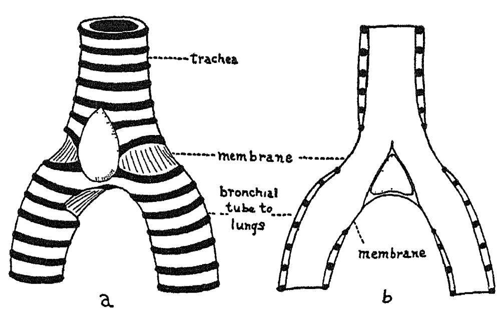


FIGURE 11

After J. A. Myers' *Studies of the Syrinx of Gallus domesticus*, Journal of Morphology, Vol. 29.

on the outer side of the trachea at the point of forking, and two on the inner sides of the fork. The tubes from the lungs carry air past the four membranes. These vibrate if the air goes rapidly enough, and make the voice of the bird.

The largest class of living mechanisms contains those that transmit motion directly from part of the body to another by systems of levers or cords. The three classes of levers occur abundantly among animals. Indeed they are all present in the human body. The ankle joint, with its tendons in front and behind, shows diagrammatically the principles of all three orders of leverage (*fig.* 12). They differ only in the relative positions of the pivot (P), the ac-

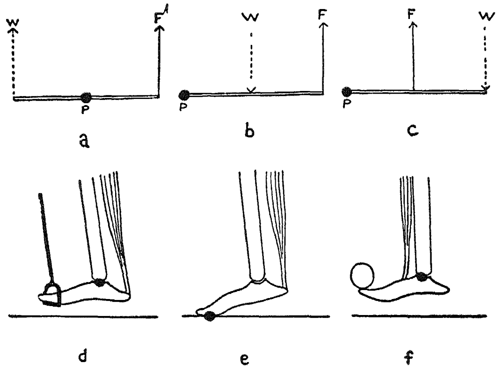


FIGURE 12

tive force (F) and the resisting force or weight (W). In the first order the pivot stands between the force and the resistance, and is assumed to be stationary (*fig.* 12, a, d). In the second order the weight (of the leg and body) is placed between the stationary pivot and the moving force (*fig.* 12, b, e). In the third order the force (a muscle which lifts the foot) comes between the pivot and the weight lifted (*fig.* 12, c, f).

We often ask the reason for the amazing strength of insects, whose muscles are inside instead of outside their skeletons. Are internal muscles mechanically more efficient than external ones? Are such muscles actually more powerful, weight for weight, than the muscles of backboned animals? Careful study shows that the mechanical advantages and absolute strength of the two kinds are practically the same. The real reason for the relatively vast power of insect muscles is their small size. The strength of muscles is proportional to the area of their cross-section, just as in the case of several ropes of different thicknesses but identical materials. It is not proportional to their length, breadth or weight. Therefore the strength of an insect cannot be compared to that of a man as the three-dimensional size is compared, but rather as the two-dimensional area of muscle cross-sections. Since area (strength) is related to vol-

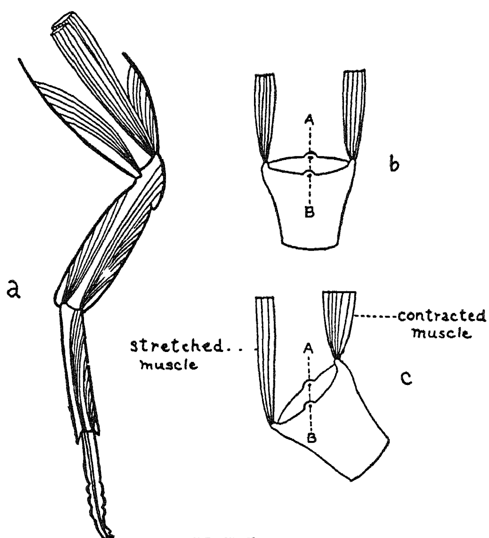


FIGURE 13

ume (size of body) as the square of a number to its cube, the strength of an animal cannot keep pace directly with the increase of the body, and the insect has the advantage.

The figures of a cockroach leg with its muscles show the same principles of leverage as in the jointing of bones and muscles in the human leg (*fig.* 13). In the insect, however, each articulation is double, since the segments of the legs are hollow cylinders; the pivoting takes place on an imaginary line through the joint, at each end of which is a point of attachment of the two segments to each other. The muscles, of course, act on

opposite sides of this axis of pivoting.

One among many kinds of mechanisms that enable an insect to perform great feats is the spring of a snow-flea (*fig.* 14). These minute insects leap on the surface of melting snow in northern forests, jumping hundreds of times their own length. The spring fits in a

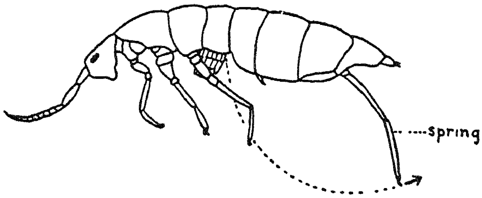


FIGURE 14

catch under the body and is snapped violently open, like the blade of a jackknife, tossing the snow-flea into the air.

The elongation of muscle into tendons makes it possible to move parts of animals that are remote from the muscles themselves. There is little space in a cat's paw for toe muscles, but the tendons from the leg run down to the last joint of each toe and pull the claw up when it is not in use or thrust it down and out for scratching (*fig.* 15). A still more peculiar use of a tendon is found in perching birds, where a cord runs down from the thigh over the knee, along the slender lower leg and around to the under side of every toe (*fig.* 16). As the bird perches on a limb its own weight, bending the leg, holds this tendon tight so that the toes are locked to the perch and even in sleep the bird cannot lose hold. In order to release its toes the bird must rise on its legs, as it does before flying.

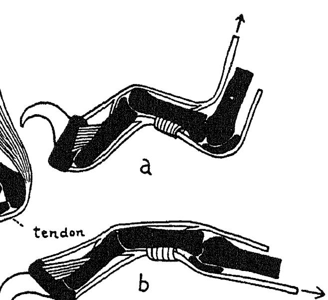


FIGURE 15

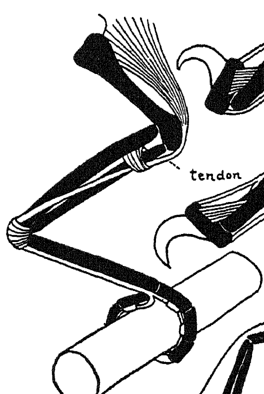


FIGURE 16

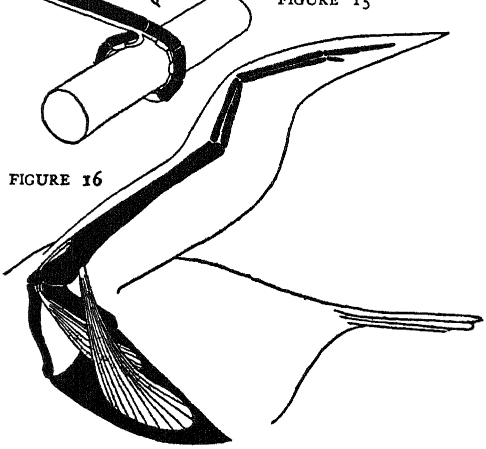


FIGURE 17

In birds, again, there is a device of pulley and tendon to lift each wing after it has been thrust down in flight (*fig.* 17). There are no large muscles on the shoulders above the wings. Instead, the great breast muscles, which beat the wings downward, have on each side a small inner division that sends a tendon up through a hole in the bones of the shoulder to attach to the upper side of the wing bone. The contraction of the inner breast muscle thereby raises the wing, alternately with that of the outer muscle, which lowers it.

Lizards and snakes share with the birds a remarkable mobility of parts of the skull. There are several extra joints among the head bones of a rattlesnake, for instance (*fig.* 18). The two halves of the lower jaw are separated at the chin, and the space between them can be stretched to help engulf an animal much thicker than the snake itself. There is a double-jointed bone attaching each side of the jaw to the rest of the skull, allowing the snake to move its jaws forward and backward as it works the prey down its throat. At the point where this extra movable bone meets the jaw there is also attached one end of a rod carrying a row of teeth and extending forward to the base of the great hinged fang. The fang, hollowed to carry venom from a gland behind the eye, is automatically flung out in strik-

ing position when the snake opens its mouth, for the lower jaw drops down on its pivot and thrusts the connecting rod up against the fang, which at other times rests in a deep pocket inside the upper lip. Moreover, as the snake strikes, gripping the prey with its jaws, the muscle which pulls the lower jaw upward at the same time compresses the poison sac and forces venom out through the fangs into the victim. This complex action may all take place in a fraction of a second, and shows that the cold-blooded, limbless serpent, is actually well equipped to compete with other creatures. There is a similar mechanism to push forward the lower

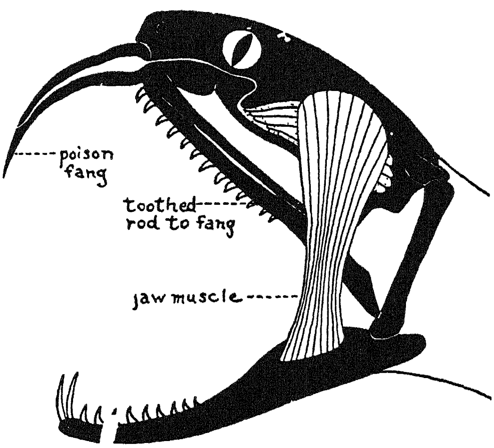


FIGURE 18

jaw and elevate the beak (instead of the fangs) in birds. Figure 19, of the parrot skull, shows this.

An elephant's trunk performs many kinds of work; heavy pushing, pulling and lifting, delicate manipulation of small objects, inhaling, blowing air or water, and "trumpeting." The trunk (*fig.* 20) consists almost entirely of long and powerful muscles, running in many layers out to the tip, and alternating with layers of tendon. There are no bones, so that all the muscles except those nearest the skull are obliged to act upon one another instead of upon the skeleton. This is a rare condition in animals. It has contributed largely to the high intelligence of elephants, for

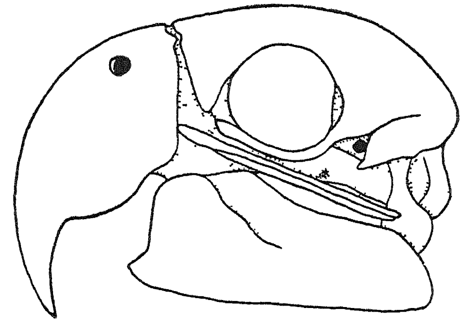


FIGURE 19

they have been able to explore their environment more successfully than the majority of animals.

Two examples of animal architecture complete this survey of living mechanisms. Both are concerned with the backbone or vertebral column, the main support of the body in fishes, quadrupeds and bipeds. Man, with his weight carried on an erect axis, is subject to great localized jarring; the whole burden of this must be borne by the spine, pelvis and legs. The diagram (*fig.* 21) shows how the vertebral column meets this responsibility by a double curve, standing vertically under the center of the skull but turning outward at the lower end to make an offset

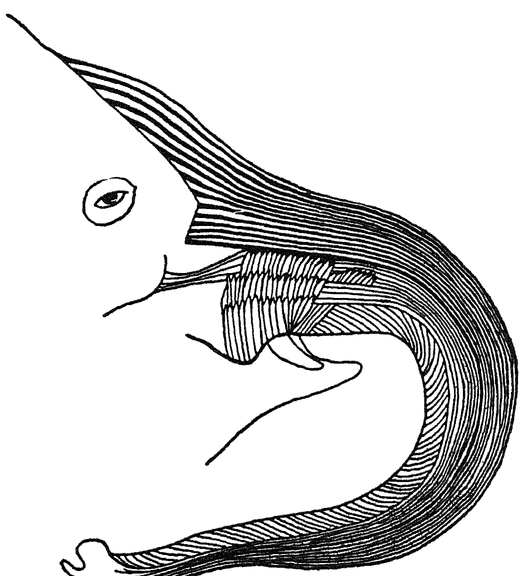


FIGURE 20

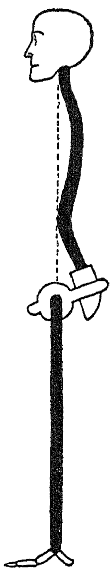


FIGURE 21

connection with the legs through the pelvis. Consequently, aided by these curves and by the cartilage cushions between vertebræ, the spine yields like an automatic shock-absorber to the weight it carries.

The four-legged beasts meet the same difficulty by suspending the backbone, with the ribs, viscera, head and tail, between the two pairs of legs just as a cantilever bridge is hung from the two pairs of towers (*fig.* 22). Instead of a series of cables radiating downward there is an elastic set of muscles sloping from the shoulders and hips. At the shoulder, particularly, the body swings as if in a hammock between large fans of muscle that run down around the ribs.

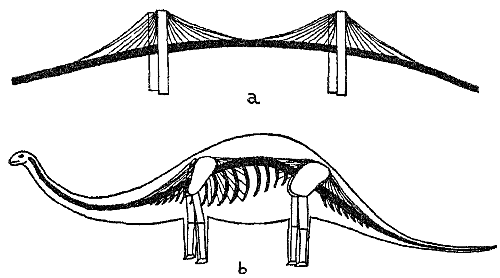


FIGURE 22

The dinosaur Diplodocus typifies the suspension bridge architecture, but the same principles apply to all quadrupeds.

HARNESSING THE OYSTER

How the Succulent Bivalve is Irritated into Creative Activity

THE CULTURE-PEARL INDUSTRY OF JAPAN

PERHAPS the peculiar fascination that the pearl has possessed for every age and race lies in the elusiveness of its charm. Try to describe it, words fail: seek the word's history, and it eludes and bewilders you in its oft-employed symbolism, "the pearl of great price", "the pearl among women", "pearls before swine". Attempt to visualize it, and moonshine, dewdrops, tears are the nearest one can get.

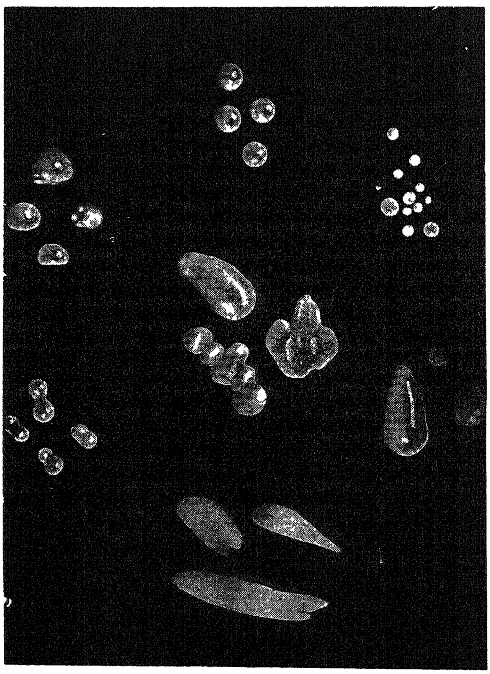
In the very earliest times, when men lived close to nature, it was believed that the pearl had its origin in a drop of dew. The Arabs have a legend that the pearl-oyster rose to the surface of the water in the early morning and drank the dew-drops, then with the breath of the air and the light of the sun brought forth lustrous pearls. In the first century Pliny writes, "The fruit of these shell-fishes are the pearles, better or worse, great or small according to the qualitie or quantitie of the dew which they received." And this origin of the pearl was very generally believed in Europe and the East up to the fifteenth and sixteenth centuries. There is an old German proverb which says, "Perlen bedeuten Tränen", and Titania's sprite

"must go seek some dewdrops here
And hang a pearl in every cowslip's ear."

But at the end of the fifteenth century, explorers of the Western World found the natives holding the opinion that pearls were those eggs of the oyster which were not cast forth but had stuck to the matrix, and were there fed unwillingly by the oyster. There was some confusion between these two beliefs up to the seventeenth century, when Réaumur first demonstrated that the pearl and the interior of the shell were of the same material. In the next century Linnæus claimed that pearls could be produced by piercing holes in the shell of the oyster with a fine auger, and in the small wound inserting an irritant, which in due course would be converted into a pearl. His secret was strictly guarded and the process lost after his death. Almost at the same time, we learn from some letters of a Jesuit missionary to China, Father d'Entrecolles, that this experiment had been tried by the Chinese as far back as the thirteenth century. This theory of Linnæus and the Chinese is one of the three commonly accepted for the formation of pearls in the pearl-oyster

The oyster, a mollusc with a very soft body, is a luxurious creature that protects himself by lining his shell with a beautiful smooth material called "nacre" or "mother-of-pearl", and he extends this covering to any object coming in contact with his body. Thus, if a grain of sand, fragment of wood, or splinter of rock should penetrate his shell, he throws over it this smooth lustrous mantle which is his defense against irritants. Nacre is formed of thin irregular layers, overlapping one another with corrugated edges, and it is the breaking and reflection of rays of light upon these edges which give to the pearl its sheen, orient or luster. Without this luster the pearl does not rank as a gem-pearl; it is greater in the true pearl than in mother-of-pearl because the curvature of the surface is greater, and the layers necessarily smaller and more broken.

A second theory of pearl formation, adopted by recent scientists, is that the pearl is the covering of a parasitic worm which enters the mollusc in its larval stage, in its growth assumes a spherical form, and then dies. Then, as M. Raphael Dubois expresses it: "the ornament associated in all ages with beauty and riches is nothing but the brilliant sarcophagus of a worm." One more explanation there is: pearls may be muscle-pearls or enveloped gall-stones, found at or near the insertion of muscles.



ORIENTAL PEARLS
BUTTON PEARLS — SEED PEARLS
FOUR PAIRS OF TWINS — BAROQUES — PEAR- AND EGG-SHAPED
BIRDS' WINGS

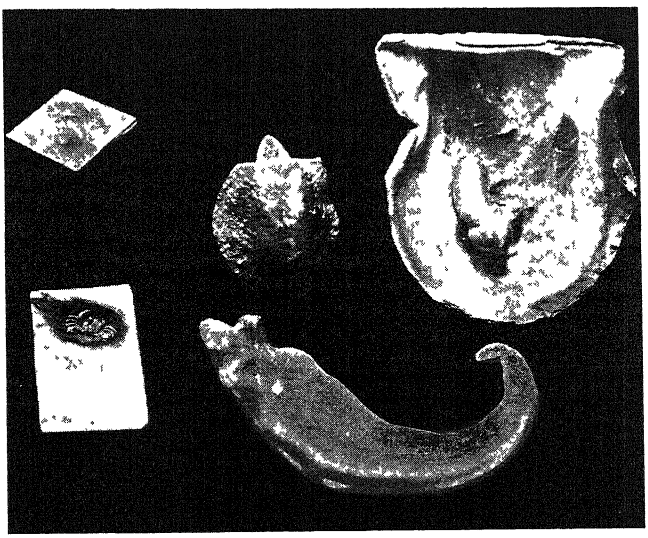
All molluscs can and do produce pearls, but it is only in the so-called "oyster pearl" that certain of the essentials of the gem-pearl are found. It must have a fine orient, a perfect skin of delicate texture; a decided color whether it be white, pink, creamy gray, brown or black; and a symmetrical form, either perfectly round, pear drop, egg or button-shaped. Sometimes the pearls are double, triple or multiple, as in the case of the famous Southern Cross; sometimes they are elongated as those found in American rivers and near the hinge of the shell. These are called "hinge-pearls". The color has no connection with the luster; it is generally the same as that of the shell-nacre, black in black, pink in pink. The most common and most desirable is white or silvery. While the Ceylon pearls are usually white, those from American rivers are noted for their variety in shade.

From earliest times, the demand for pearls has been great, particularly in the East. The Japanese call the pearl one of "the seven costly things" (*Shippo* or *Nanatsu-no-takara*). Their price has fluctuated in the West according to the more fickle fashions prevailing there, but they have never at any time been without considerable value, and today rank among the most precious gems. There was the danger that the pearl fisheries might become exhausted, and efforts have been made to keep up the supply by artificial means.

One of the dreams of medieval alchemists was the creation of pearls. We possess two ancient Greek treatises, one of which tells how to clean true pearls, and the other how to make them artificially by a *tour-de-main* founded on the properties of chloride of mercury. In 1680 Jacquin, a rosary-maker of Paris, succeeded in making false pearls by encrusting molds with fish-silver. But the culture of the true pearl was first discovered by the Chinese. Ye-jin-yang, a native of Hoochow, in the thirteenth century started the industry by cultivating the river-mussel, and today near Teh-tsing it forms the staple occupation of several villages, employing as many as 5000 people. In Chung-kwano, the center of the pearl culture, a temple has been erected to the memory of the originator of the trade. Father d'Entrecolles writes an amusing letter in 1734, describing how the Chinese "put the mussels in fresh water where the dew fell, where no female could approach, nor barking of dogs nor crowing of chickens be heard". Small round pellets of the size of a pea, formed of pulverized seed pearls moistened with holly juice, were inserted into the valves and the mussels put back into the water for a certain time and fed.

Later the shells were again opened and the pearls extracted. However, the best of these Chinese pearls are of inferior quality and valuable only as curios.

No greater result was achieved by Linnæus in Europe, though the incentive of his experiments was not lost. Similar attempts have been made in the United States, the Ceylon fisheries, in Saxony, Sweden, Finland, and in Japan. Dr. Louis Bouton in 1897 succeeded in producing pearls in the abalone, this being a very hardy species for experimental purposes. He was so successful that it is probable that some day there will be a profitable business in growing pearls in abalones on the Pacific Coast of the United States. Mr. Vane Simmonds of Cedar Rapids, Iowa, experimented in a way calculated to save the strain on the oyster's muscles, and thus produce a healthier pearl. He caused the oyster to open under the influence of air and sunshine, then inserted a small wooden wedge and immediately immersed the oyster to revive it. After a few minutes the mantle was raised, a pellet of wax put in and the mantle slipped back as the creature was returned to the water.



BLISTER PEARL WITH CRAB INSIDE

BLISTER PEARL SPLIT OFF TO SHOW CRAB INSIDE

BLISTER PEARL SAWN OFF TO SHOW A BIVALVED SHELL INSIDE

CURIOUS FORMATION OF AN ABALONE PEARL

BLISTER PEARL WITH MUD INSIDE

To a Japanese, however, belongs the glory of achievement in the culture pearl. Mr. Kokichi Mikimoto of Toba, in the province of Shima, realized that the valuable Japanese pearl fisheries were being exhausted and began to cultivate the oyster. He exhibited some specimens of pearl oysters in the third National Industrial Exhibition of Tokyo, and there with Dr. Mitsukuri, professor of zoölogy in the Imperial University, first conceived the idea of cultivating pearl oysters for the production of pearls by the use of the right stimuli. Like most discoverers and inventors ahead of their age, Mikimoto had the usual disappointments, difficulties and failures, accentuated in his case by the unbelief and ridicule of his friends. He persevered, however, through eight long years, changing his methods a little, shifting his experiments, and at last believed he was justified in putting out a trial crop. It proved encouraging and he tried another and another, each time gaining ground in his quest of the pearl of great price, until now he produces culture pearls on a commercial scale.

Just out of the sweep of the great Gulf Stream, though near enough to feel its warmth, lies the sheltered Bay of Ago, a quiet body of water 12 miles wide, 6 miles long and 10 fathoms deep. This was the field chosen by Mikimoto for his enterprise, and he first leased the sea-bottom around the island of Tatoku. As the work prospered he increased the farm, until now it comprises some 50 nautical miles. The people employed in the fishery — several hundreds of them — make their homes on the island. Women do the diving, for they can remain submerged longer than men. Girls begin when they are fourteen years old, and become most valuable divers between the ages of 25 and 35. No greater contrast to the armored diver of aquarium and pictured adventure could be presented than the white-clad "sea-girls" of the Bay of Ago.

The sea girls wear a simple costume of white cotton knickerbockers, short skirt and blouse. Their long black hair is twisted up into a tight knob on top of the head, and a white cloth drawn over it. Special diving glasses to protect the eyes from the salt water are worn, but beyond these no other protection. Suspended from the waist of each woman is a small tub, into which she throws the oysters, which are later tipped into the boat. No weights are used as in the Persian Gulf and Ceylon fisheries; here they sink to the bottom, where they remain from 60 to 80 seconds.

MR. KOKICHI MIKIMOTO
The first to make a commercial success of culture pearls.

Work generally begins by sunrise, when the divers are taken out to the beds in large flat-bottomed boats, and landed on rocky projections from which, if the water is deep enough, they take their plunge. They utter curious hoarse whistling sounds both as they sink and come up. It is an exhausting occupation so the hours can not be very long; six to eight is the maximum. Most of the diving is done between March and December, as the sea is too cold in January and February. Wages are low when judged by our own standards. An experienced worker can bring up 10 oysters from 10 fathoms in 60 seconds.

The methods of pearl culture as worked out by Mikimoto are easy to follow. The pearl oysters found in the Bay of Ago belong to the species *Margaritifera martensii*, which is rather small in size with a thin shell.

They are found at a depth not greater than 10 fathoms, anchored to rocks, stones and stems of sea-weed by a thread which the animal secretes. They live for about 12 or 13 years only. In July and August, the workers place small pieces of rock and stone in shallow waters where oyster larvæ abound. Very soon small oyster spats become attached to them, and these with their anchoring rocks are moved to deeper waters, where they can be kept warm during the winter months. After three years the oyster is sufficiently strong and grown to be brought to land and operated upon. The shells are opened, and small pearls or round fragments of nacre put in, to form the stimuli round which the oyster will build the pearl. Then the shells are put back in the oyster-bed, each being allowed a square foot of space.

For four long years, they lie undisturbed by man, but as subject to loss as the Argosies of old into which the Venetians put all their fortunes. The octopus and the star-fish prey upon young oysters: the "red current" *akashiwo*, or plague of microscopic organisms fatal to marine creatures, often sweeps through these waters; the choking sea-weed *mirumo* grows fast to smother them; the nuclei wash out. All these and many other evils are incident to the life of the oyster, or the growth of the pearl. At the end of the four years the divers bring up the shells, which reveal 5 to 7 pearls of marketable value in every 100 opened oysters. They are generally attached to the inner surface of the shell and have to be cut out, when they exhibit the essentials of true Oriental pearls in luster, texture and color. For some years the culture pearl grew only like a button, but in 1905 Mr. Mikimoto solved the problem of the round pearl, which gained a medal in the Tokyo Exhibition in 1914.

"The pearls possess in a marked degree all the features of the finest natural gems, with the enchanting satiny luster, and the tender iridescent rose and faint blue sheen aimed at but never attained by the makers of imitations. The shifting play of these exquisitely delicate tints is much like that of a faultless opal, which sends a deep flame from its heart rather than from its surface."

HEATING AND VENTILATING

Importance of Controlling Temperature, Humidity, Purity and Movement of Air within Buildings

MODERN AIR CONDITIONING METHODS

THE subjects of heating and ventilating and to some extent that of refrigeration may be summed up in the words *air conditioning*, an expression coined by Willis H. Carrier, and defined by him as "the science of mechanically controlling temperature, humidity, purity and movement of air within buildings or enclosures, thereby controlling the effects of such air upon persons and materials exposed to it." The importance of the subject is growing daily as its economic advantages become better recognized. It applies to all kinds of habitations, to the manufacture of all sorts of hygroscopic materials, to the preservation of foods, to dry kilns and to the storage of many materials.

In some cases the control of temperature alone is necessary, in others that of humidity is the most important factor, but, in an increasing number the control of temperature, humidity, purity, and air movement is an economic necessity. Some of the more important applications may be enumerated as follows: textile manufacturing, lithographing and printing, paper making and storage, tobacco manufacture, storage of leather and manufacture of leather products, bread and candy making, theaters and auditoriums, office buildings, stores, etc.

A single rayon plant at Covington, Va., has a capacity of 6,000,000 pounds of rayon per year. The manufacturing process requires ageing of the viscose at 25°F after which it is extruded through minute holes into a sulphuric acid bath which forms the thread. It then goes through the four separate steps of spinning, twisting, bleaching and drying, and finishing. In each of these steps, close but independent regulation of temperature and humidity is necessary to obtain the commercial standard of rayon.

News print paper should contain 9 per cent of moisture for best printing results. This requires close regulation of storage rooms. Leaf tobacco can be handled only when the humidity is right, so that, without its control, the tobacco could be handled only when the weather was favorable. Much time was formerly lost each day in shoe factories to get the leather moistened up in proper condition to work. Now it is stored in rooms where the regulated humidity keeps it constantly in condition for immediate use. Mr. Carrier stated that humidity control has been highly responsible for the vast textile manufacturing development in the south.

Theater managers, office superintendents and store owners are coming to recognize more and more the business value of proper air conditioning. The J. L. Hudson Co of Detroit pointed the way by installing, as part of the original equipment, air conditioning apparatus for the main, the mezzanine and the basement floors of this department store building erected in 1924–25. The management is quoted as having recently said: "We consider air conditioning absolutely essential for our basement floors."

The New York State Commission on Ventilation found that even slight overheating, say to 75°F with 50 per cent relative humidity, causes discomfort and premature fatigue. It increases body temperature and heart rate. Piece workers, paid a bonus for quantity work in addition

to a flat wage, did 13 per cent less work at 75°F than at 68°F. This, without reference to the quantity of air supplied or the CO_2 content; a rise to 86°F under the same conditions of relative humidity decreased production 28 per cent.

Mr. W. F. Snow pointed out that the records of the U. S. Pension Bureau showed that when the offices were located in scattered and poorly ventilated buildings, 18,736 days were lost per year, by illness and that when the Bureau became housed in new and well ventilated quarters the loss dropped to 10,114 days with a larger force employed.

Dr. C. E. A. Winslow in an article on "The Cash Value of Factory Ventilation" made the following statement: "Efficient production requires skilled and practiced workers, in good physical condition, applying themselves with energy and enthusiasm to their tasks. Irregularity of attendance and the physical sluggishness and nervous inattention which accompany lowered vitality mean direct money loss to the employer of labor, as well as a burden on the community at large."

In this age of high speed production with a reduction in the number of working hours it is of increasing importance that the workers be placed in an environment which will keep them physically fit and mentally alert.

Heating

In climates where the temperature drops much below about 65°F for any considerable period during the year the use of some kind of artificial heat becomes necessary. The earliest applications of artificial heating consisted of open fires of sticks and leaves built in positions of natural shelter from the storms. Later tents or crude huts were erected with holes in the roofs to allow the smoke to escape. Abundant ventilation was afforded in these huts through numerous cracks and openings in the walls. As buildings became better constructed, the open fire was supplanted by the fireplace which was constructed of stone and the chimney or opening to the outside extended only a few feet above the ground.

The early castles of England were in general heated by a central fire in a great hearth, somewhat on the order of an altar, upon which charcoal or coke was burned. Stokes Castle which dates from the 14th century was heated in this manner; and even as late as the 18th century, open braziers burning charcoal or coke were to be found in London in the House of Commons. Later, chimneys were built extending to the tops of the houses and having the same cross-section all the way up. From these have developed the modern open fireplace and grate, constructed often as ornaments and to impart an air of cheerfulness to the rooms, as only about 10 or 15 per cent of the heating value of the fuel is utilized.

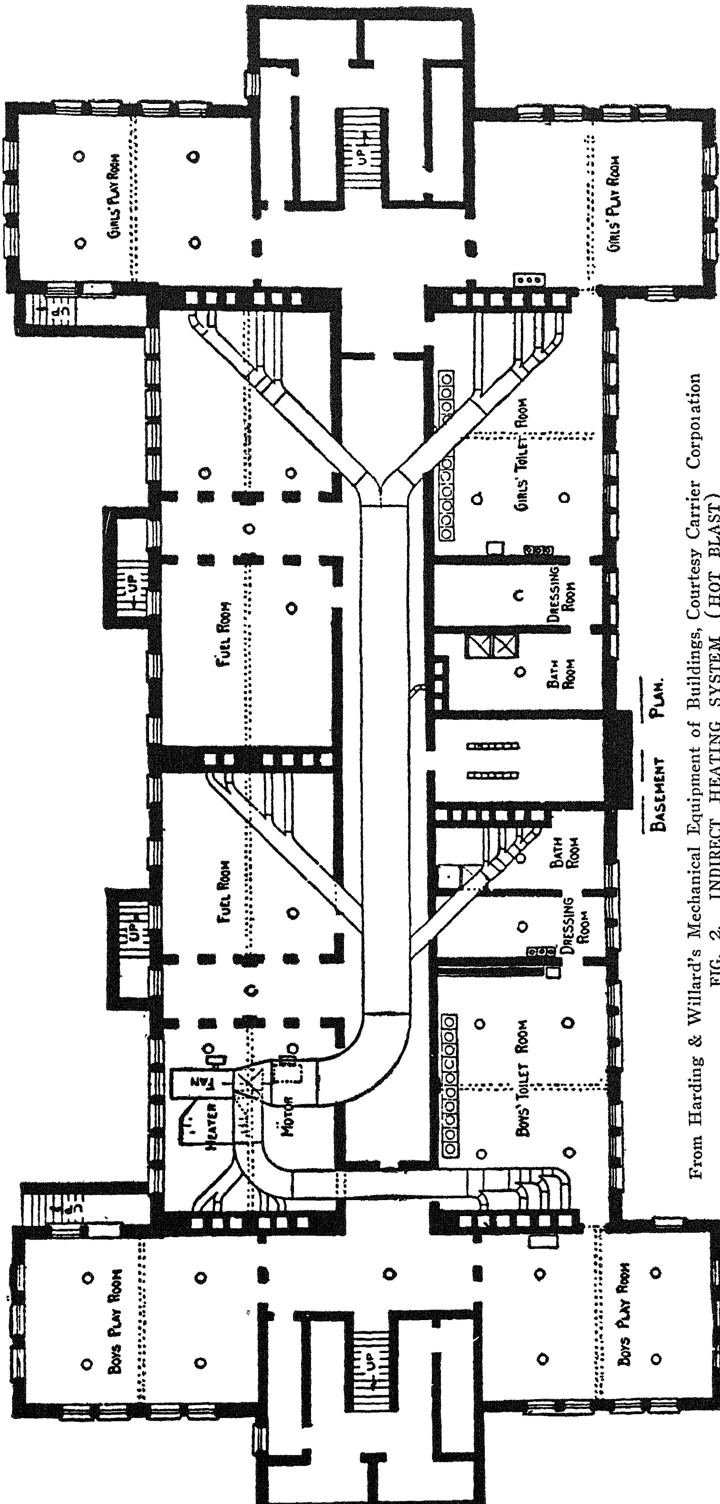
Then followed the hot air furnace (for the invention and application of which Benjamin Franklin is credited), the steam, hot water and blast heating systems.

In general there are two classes into which heating systems may be divided: direct and indirect. In direct heating the apparatus is placed in the room to be heated and gives off its heat by radiation and by convection. Under this class, grates, stoves, radiation systems and electric heaters fall. Indirect heating includes those systems in which the air to be supplied is heated at some outside point and carried to the rooms through ducts or pipes. This class includes furnace, fan, hot blast, plenum or pressure systems, and is the kind usually employed for large auditoriums and in places where positive ventilation is a necessity as, for example, in large school buildings, theaters and churches.

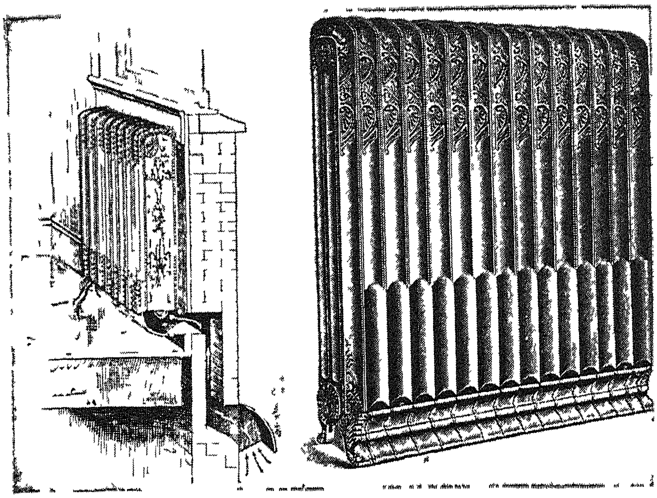
Then there are two other systems that do not fall clearly within either of these classes. One of them is that in which the so-called radiator is placed within the room to be heated, but is inclosed in a jacket, except for the lower portion of the front side, where the air, drawn from outside through a connection at the back and which has passed over it, is permitted to enter the room. This type is called direct-indirect heating and it is widely used in various modifications. The other type is known as panel heating. It is much used

in the best classes of European buildings and has been introduced into this country within the last few years. It consists of a very large area of coils of small pipe (usually ½ inch) imbedded in the plastering either of the walls or, preferably, of the ceiling and heated by hot water pumped through them. Rooms so heated show no sign of any heating system at all. If the coils are placed in the ceiling practically all the heat supplied is true radiant heat and the room temperature may be several degrees lower, for the same degree of comfort to the occupants, than that of the usual system in which the rooms are heated largely by convection. This is because the radiant heat warms the objects in the room and the air is warmed by contact with these objects and is therefore cooler than the objects.

Quite the reverse is true when heating with the usual steam or hot water radiators. Here, although they are called radiators, more than half of the heat supplied by such equipment is given off by convection, the particles of air being heated by direct contact with the radiator. In this case the air is warmer than the ob-



From Harding & Willard's Mechanical Equipment of Buildings, Courtesy Carrier Corporation
FIG. 2. INDIRECT HEATING SYSTEM (HOT BLAST)
Basement of large school fitted with Green heating and ventilating apparatus.



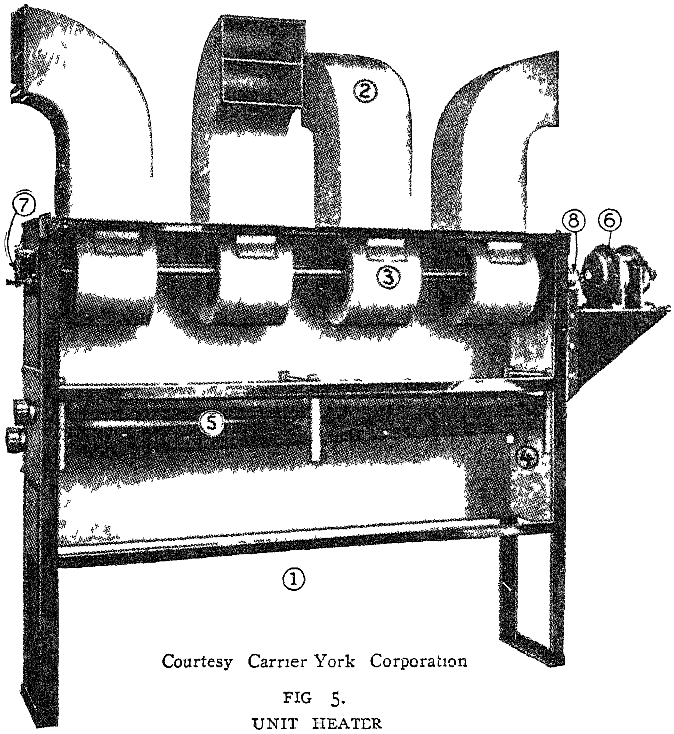
Courtesy John Wiley & Sons

FIG 3 DIRECT-INDIRECT RADIATOR.

jects in the room. However, it is doubtful if panel heating will ever become very popular in the more rigorous climates of the northern United States and Canada.

Unit heaters

A new type of heating system which has developed very rapidly in the last few years is what is called the "unit heater." It is employed chiefly in factories and all kinds of industrial plants where large undivided areas are to be heated. It may be classified with direct heating. The unit consists of a heating element or coil, through which steam or hot water is passed, and a fan to draw the air over it and discharge it at a high velocity, usually in a nearly horizontal direction, just above the heads of the occupants. There are several advantages in this type of heating: a single unit can heat a large area, it is less expensive to install and lighter in weight than a radiator system, it takes the air from near the floor where it is coolest and discharges it, after heating, with sufficient velocity to keep the air in the room in motion—thereby



Courtesy Carrier York Corporation

FIG 5.
UNIT HEATER
(The front side of the casing has been removed in order to show the interior of the unit)
(1) Air intake near the floor (2) Hot air discharge outlets, (3) Centrifugal fan, (4) & (5) Steam heating coils of copper with extended surfaces, (6) Motor for driving fan

avoiding the very annoying temperature gradient which is usually experienced with direct heating. That is, there is a tendency with the latter for the warm air to collect at the top of the room where it is not needed and not desired. The room temperature is usually observed at the "breathing line," a point five feet above the floor. Above this plane the air grows warmer with increasing elevation and below it the air grows colder toward the floor. From the point of comfort and convenience the reverse order would be more desirable. It has been found in practice that there is an increase in temperature with elevation of about 2 per cent per foot. With high ceilings the mean temperature of the room is likely to be several degrees higher than that at the breathing line. Since the heat loss from the room is proportional to the difference between the mean temperature of the room and the outside temperature it is desirable, from the point of economy, to keep the temperature gradient as low as possible. Without some positive movement of the air this large temperature gradient can not be avoided. If, as sometimes happens, the leakage of air around the windows of a building is insufficient to supply the necessary fresh air for ventilation the intake of the unit heater can be connected to the outside so as to draw all fresh air from the outside or a part from the outside and part from near the floor in the building as the demand for ventilation may require. Unit heaters make an undesirable boiler load unless the boiler is supplying a large amount of steam or hot water for other purposes or unless some special arrangement is made to take care of the large fluctuation in load when the heaters are started up and closed down, especially if this is done automatically.

Vacuum or vapor systems

There are many trade names applied to heating systems operating at pressures below that of the atmosphere. They are in principle all alike, the difference being in the manner of control. Any properly designed system must have sufficient capacity to meet the most severe weather that is likely to occur in the climate in which the installation is made. This demands a larger system than is required for a great part of the heating season so that the heater is operating under light load the major part of the time. With the ordinary steam radiator system there is no heat in the radiator at all until the temperature in the boiler is brought up to about 212°F, when steam begins to circulate and the surface of the radiator soon assumes approximately the same temperature. Now so long as

the temperature of the radiator remains constant at 212° and the temperature of the room remains constant at 70° there will be a constant quantity of heat given off to the room by the radiator. This is about 240 heat units per square foot of radiator surface per hour. If this amount of heat is necessary and sufficient to keep the room warm, that is to balance the heat loss from the room, during the coldest weather then at all other times there will be an excess of heat coming from the radiator and the room can be kept down to 70° only by opening windows. Opening the windows creates a draft over the radiators and increases the quantity of heat given off by them so that it sometimes occurs that more heat is used during moderate than during extremely cold weather. This means a corresponding waste of fuel. Of course the steam pressure could be increased to say 10 pounds during the cold weather and dropped down to about that of the atmosphere during moderate or mild weather and this would decrease the temperature of the radiator during mild weather by about 27° but would decrease the heat supplied by the radiator only about 16 per cent while the heat loss from the room, and therefore the demand for heat, might have decreased 85 per cent or more. On the other hand a corresponding decrease of pressure in the radiator, that is to about 20″ of vacuum, which is easily attained with almost any vacuum pump, would reduce the radiator temperature about 50° and reduce the heat supplied by the radiator about 35 per cent. From this it is evident that reducing the pressure below that of the atmosphere is much more effective than increasing the pressure above that of the atmosphere, and this is the primary reason for employing a vacuum or vapor system.

Its use requires a special valve or trap, as it is called, at the outlet of the radiator to prevent steam from passing through into the return line and being wasted, as well as disturbing the action of the pump. These traps remain open when cold, but close quickly when surrounded by steam. The simplest form of vapor system is the mercury seal which has been extensively used and it requires no pump nor aspirator to produce the vacuum. The air vents from the radiators are connected to a vertical pipe leading to a mercury well. The vents are thermostatic so that air can pass out but steam can not, and the air is blown down through a shallow depth of mercury and escapes to the atmosphere while the system is being heated up. As the fire in the boiler dies down and the steam condenses in the radiators a partial vacuum is formed and the temperature of the radiators drops correspondingly. If the plant is tight and a low fire is maintained the radiators will remain at a moderate temperature.

The vapor system is not any more efficient than any other good one, but it makes possible a reduction in the amount of heat used during moderate and mild weather. Furnace and hot water systems have even greater flexibility in this respect.

Indirect heating by fan

In general in the larger indirect heating systems the heating unit with the fan is located at as nearly a central point in the basement as practicable, and the heated air is driven through appropriate ducts or pipes to the rooms.

Various arrangements of distribution are used. The simplest is what is known as the trunk duct system (see Fig. 2) in which all the heated air is carried in one or two large ducts with branches leading off to the various rooms. The main duct is, of course, reduced in size as the branches take off. Then there is the individual, sometimes called the single duct system, in which a duct of suitable size leads from the main heater to each room. This makes it possible to control, usually done automatically by a thermostat, the temperature of each independently. This is done by mixing, at the entrance of the duct, cool air with the hot air in just the right proportion to keep the temperature of the room at the desired point.

In other systems the fan is located in a central point but the heaters are distributed so as to be at or near the rooms. These heaters may be located in the basement and each supply heat to a vertical stack which leads to a group of rooms one

above another or there may be a heater placed in the wall at the entrance to each room.

With the heaters distributed in the basement the temperature of a whole vertical section of the building is controlled by regulating the supply of steam or hot water to the heater and a thermostat centrally located in this section of the building controls the temperature of all the rooms in that section.

With the individual heaters each room has its own thermostat. In cases in which different parts of a building are used at different times or for different purposes, a separate fan is used for each section of the building so as to avoid operating the whole plant when only a part of the building is in use.

In still other systems a heater with individual fan is placed in the wall of each room and the air supply is taken either from the outside or from near the floor of the room itself and the heated air is blown into the room. This type operates on the same principle as the unit heater. In all of these systems air may be recirculated when fresh air is not needed for ventilation, and thereby a great saving in heat is effected.

In many buildings direct and indirect heating are combined. The direct radiators supply an equivalent of the heat loss from the building while the indirect system supplies the air for ventilation. In such cases the air blown into the rooms is only heated to a temperature slightly above that of the rooms and the indirect system is shut down when the rooms are not occupied.

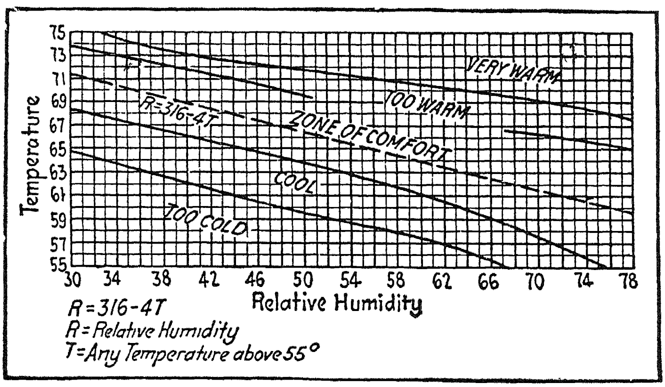
Ventilation

The first efforts on record of a serious attempt to ventilate a building were made by Sir Christopher Wren, in 1660, to ventilate the English House of Parliament. In 1812 Sir Humphry Davy, in one of his lectures before the Royal Society, submitted a model, which he had prepared at the request of Lord Livermore, illustrating a plan to ventilate the House of Lords. The plan was carried out and when it failed to produce the desired results Sir Humphry became the victim of much ridicule under which he chafed greatly. The only known means of producing draft at that time was by a chimney with a fire at the base to augment circulation. The early idea in regard to ventilation was to get an abundant supply of fresh outside air to take the place of that supposed to be contaminated by organic matter given off by people, by an increase in the carbon dioxide content and by a depletion of the oxygen. Such incidents as the death of 113 out of 146 men in the Black Hole of Calcutta on one hot June night; of the death of 72 out of 200 passengers shut in a small cabin of the ship *Londonderry* during a storm, gave color to these beliefs. It was not until about the beginning of the present century, after elaborate and prolonged experiments had been conducted in various countries of Europe and in America, that the last vestige of fear of "crowd poisons" disappeared. Such fatalities as those mentioned above can now be accounted for on the basis of temperature.

The human body is a generator of heat which passes from the body by convection, by radiation and by evaporation. Convection takes place when particles of air cooler than the body receive heat by contact with it, and then pass off carrying the heat with them. Heat is dissipated by radiation when the walls and the surrounding objects in the room are at a lower temperature than the body. Evaporation occurs when the skin is moist and the air is sufficiently dry so that it can readily absorb moisture. If the air temperature is equal to or above that of the body no heat can be carried away by convection. If the walls of the room and the objects in it are as warm or warmer than the body no heat can be dissipated by radiation. The moisture on the skin is in the form of water and that in the air in that of vapor. In passing from the body to the air this moisture must absorb the latent heat of vaporization and thereby extract large quantities of heat but, if the air be saturated no heat can be dissipated by evaporation. If then, a room have a temperature only a few degrees above the normal temperature of the body, and the air be saturated, a human being can not long live therein.

In 1910 the Chicago Commission on Ven-

tilation was organized and undertook as one objective the determination of the most favorable temperature and the most favorable humidity for comfort in school-rooms. They fitted up a room so that distribution of the air supply throughout would be perfect and so arranged it that both temperature and humidity could be independently controlled. In this room, which was then used as a classroom, they conducted experiments making use of the independent judgment of the students and the teacher as well as of the experimentors as to the degree of comfort for the various combinations of temperature and humidity. It soon became evident that there was no fixed temperature nor humidity required for comfort but, that a proper relation between these two variables would give comfort over quite a range. The result of this work was published in 1914 and the chart, Fig. 6, which formed a part of this report, attracted much attention and was widely copied. It does not take account of air movement and it was soon found that there were occasions when, with the relation of temperature and humidity in accordance with the comfort zone, the occupants complained that it was too cool. Further experiments were made by the Commission to study the influence of air motion, after which the subject was brought to the attention of the American Society of Heating and Ventilating Engineers who deemed it of sufficient importance for a special problem to be thoroughly explored. This was



Courtesy The Aerologist

FIG. 6. COMFORT CHART.

done in their laboratories at the U. S. Bureau of Mines in Pittsburgh and part of the results were published in the form of psychrometric charts of which Fig. 5, for still air, is an example. The new feature added to the well-known Carrier humidity chart was the effective temperature lines.

Effective temperature may be defined as a measure of the sense of heat experienced by the human body as a result of any combination of temperature, humidity and air motion.

Rooms or enclosures have the same effective temperature if the combined effect of temperature, humidity and air motion produces the same sense of heat upon the human body in each.

The human body, and probably that of any warm-blooded animal, is affected by changes in the rate of heat loss from it. The effect of a change in the temperature of the surrounding air, which would ordinarily change the rate of heat loss from the body, may be neutralized by a simultaneous change in the humidity, in the air motion or in both. It is therefore possible to vary the temperature, the humidity and the air motion through a considerable range without affecting the sense of heat upon the body.

The *optimum effective temperature* is the effective temperature which gives to the average person the greatest feeling of comfort. This will of course vary with the occupation of the subject experimented upon and with the weight of clothing worn. It was found at the A. S. H. V. E. Testing Laboratory that 95 per cent of a large number of subjects at light exercise and normally clothed considered 64°F the optimum temperature. The scale chosen for measuring effective temperature in still air is the same as that of the wet bulb temperature on the saturation curve. Any point along an effective temperature line, as the 65° line on the chart, will give to the body an equal sense of heat even though the actual air

temperature varies greatly. For the 65° line this variation is from 65°, as read on the scale at the bottom, to slightly more than 73°. Moving air carries away more heat by convection and, except when it is saturated, it also carries away more heat by evaporation than does still air, so that a different scale for effective temperature must be used for air in motion.

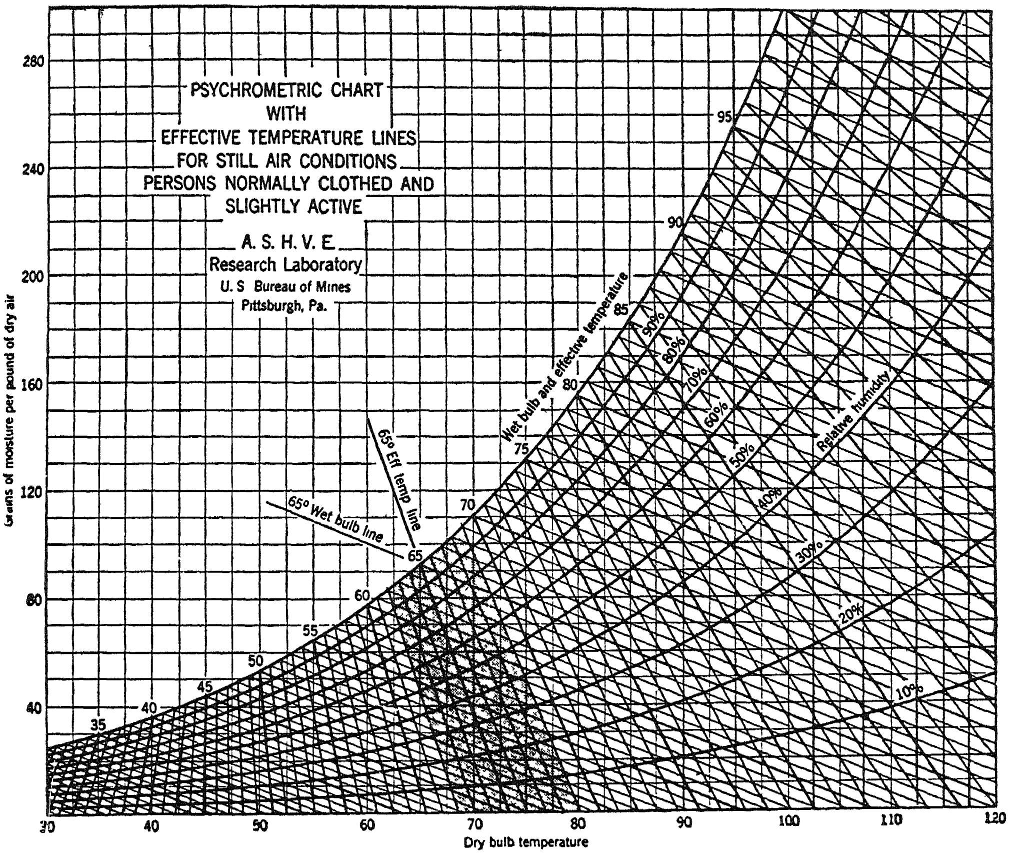


FIG. 7. PSYCHROMETRIC CHART WITH EFFECTIVE TEMPERATURE LINES FOR STILL AIR.

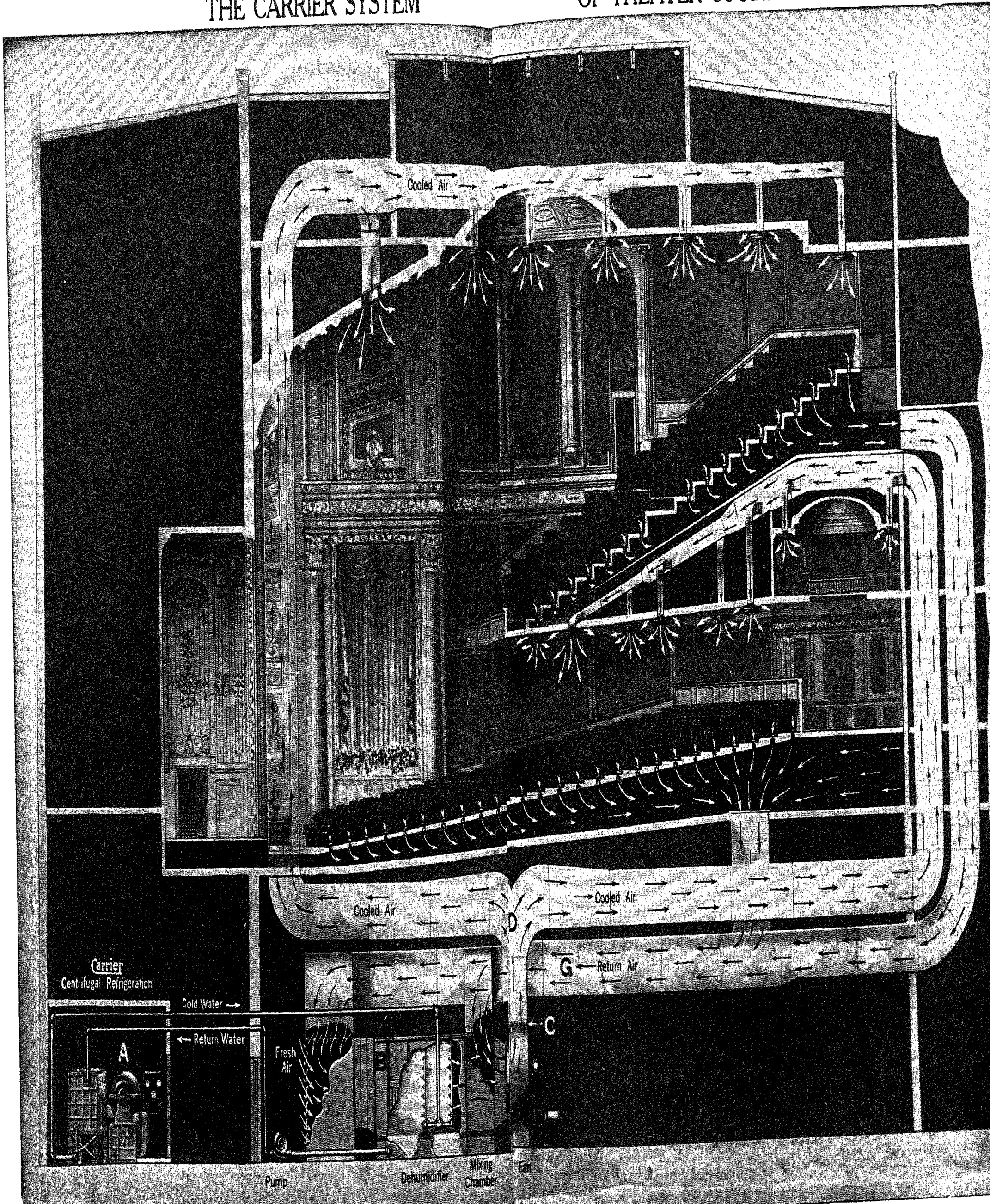
Cooling

For some industrial purposes, as in candy making, cooling of the air in summer is quite as important as heating in winter. In a very limited number of industries cooling has been practiced in a crude way for many years, but it was not until 1902 that it was applied on a large scale for human comfort. This was in the New York Stock Exchange. It is reported that the architect, Mr. George B. Post, in trying to sell the idea of a cooling system to the building committee made the following comment: "When it is possible to freeze dead hogs in the Chicago Stock Yards it ought to be possible to cool live bulls and bears in the New York Stock Exchange."

Cooling was applied only to the main floor and the basement of this building and the contract price for the equipment, exclusive of ventilating fans and ducts, was $123,000. Three refrigerating machines, each having a cooling capacity equivalent to that of 150 tons of ice melted every 24 hours, were employed.

Although the economic advantages of air conditioning for human comfort are less tangible than those for many industrial applications they are nevertheless real. Mr. R. W. Pryor states that the air washing equipment, which is also a cooling apparatus, installed at the Bloomfield Plant of the

THE CARRIER SYSTEM OF THEATER COOLING



A. The Carrier Centrifugal Refrigeration unit which cools the water for the spray chamber.
B. The spray chamber or dehumidifier where the air is dehumidified, cooled and cleansed.
C. The centrifugal fan which draws the air through the spray chamber and passes it through metal ducts to the theater.
D. The large metal ducts through which conditioned air is passed to the ceilings of the theater.
E. The downward diffusion outlets through which the air is diffused over the audience, reaching the Breathing Zone first with complete absence of draughts.
F. The chambers beneath the balcony and orchestra seats into which the air is drawn from the theater.
G. The large metal ducts through which the used air passes back to the spray chamber to be rewashed, cooled, dehumidified and mixed with fresh air.

Courtesy Carrier Corporation

Westinghouse Lamp Company speeded up production and at the same time decreased the cost of labor turnover by an amount estimated at 10 per cent. He also states that the investment, although heavy, paid for itself in the first season.

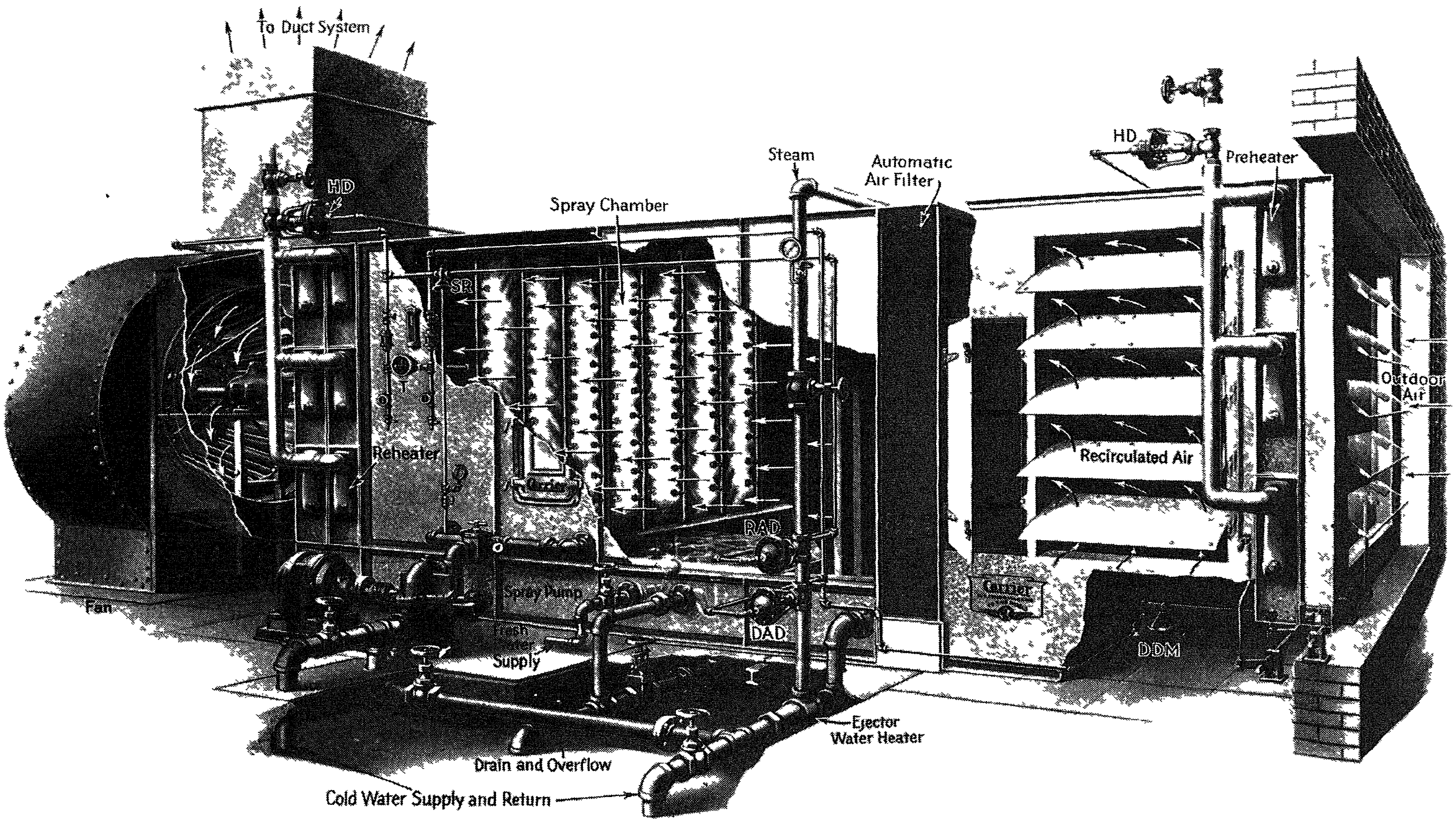
Theater managers were quick to recognize that an efficient cooling system made the difference on hot, sultry days between having their houses full or nearly empty. The early applications of cooling in theaters were, however, overdone, as an attempt was made to have a temperature of 70° in hot weather the same as for winter. This proved unsatisfactory as such a sudden change produced a feeling of chilliness on entering the building and of unbearable heat on leaving it.

The process of cooling is not so simple as it may seem because as the air is cooled its humidity rises until it becomes saturated and then no further cooling occurs until some of the vapor is condensed and the heat of vaporization extracted. If the cooling be accomplished by contact of the air with cold surfaces, as cold brine coils or the expansion coils of some refrigerant, as ammonia, the moisture condensed from the air is deposited on the cold surfaces and those surfaces soon become covered with ice. The more practical way of cooling air is by washing it with sprays of cool water. This method makes control of the moisture content of the air absolute and easy. All that is necessary is to control the temperature of the water spray through which the air is passed. The air will then be saturated and at the temperature of the water spray. When the air is heated after leaving the spray its relative humidity decreases as the temperature increases. It is possible then to obtain any relative humidity desired by simply fixing the temperature of the water spray and the final temperature of the air after it leaves the spray chamber. In winter heat must be added to the water by steam coils, or otherwise, to keep the cold air from cooling it below the desired point and then the air must be reheated to at least the temperature of the room it is to ventilate. In summer the spray must be cooled by brine coils or otherwise. In the spray chamber the water from the sprays falls into a tank or sump at the bottom, from which it is pumped again to the spray nozzles and all that is necessary to control the temperature of the air leaving the spray chamber is to control the temperature of the water in the sump. In winter the water temperature is kept up by admitting steam to coils in the sump. In summer the water is kept cool by circulating cold brine through coils in the sump. In both cases the temperature is automatically controlled by thermostats.

After the air leaves the spray chamber it passes through eliminators to remove water carried in suspension. It then passes through a fan, and in winter through a reheater, where its temperature is brought up to or above that of the room it is to ventilate, after which it is carried by an appropriate duct to the room. In summer the cool air from the eliminators may be blown directly to the room, which it enters at the top through diffusers, and settles through the room mixing with and cooling the air therein. Of course as much air passes out of the room as is forced into it. This air is either returned to the spray chamber or is allowed to escape to the outside through vents provided for the purpose.

As examples let us assume that the system is used for ventilation only, direct heating being used to balance the heat loss in winter; and that in winter the air must enter the room at a temperature of 68°F, and have a relative humidity of 50 per cent. Under these conditions, 1 pound of entering air would carry 51.5 grains of water vapor. The temperature of saturated air to carry this amount of vapor would be 49° and this is the temperature at which the spray water would have to be kept. Again assume that for a maximum summer temperature outside of 95° and a relative humidity of 60 per cent it be required that the air entering the room shall have a temperature of 80° and a relative humidity of 75 per cent. The weight of vapor carried by the air as it enters the room would be 117 grains per pound of air and the temperature of the spray would have to be kept at 71.5°. The amount of moisture to be condensed out of each pound of air would be 37 grains. It

TYPICAL CARRIER CENTRAL STATION AIR CONDITIONING UNIT



Courtesy Carrier Corporation

FIG. 8. AIR WASHER

An effective cooling system when the water is kept coo

would require the extraction of 1.4 times as much heat to condense the vapor as it would to cool the air. This is the reason why air cooling is so expensive. A material saving can usually be effected by re-circulating most of the air and only taking a small part of fresh air from the outside. The air leaving the room will carry heat and moisture, in addition to those which it carried upon entering the room, equal to the heat given off by lights, or transmitted through the walls from the outside, and the heat and moisture given off by the occupants so that, even with re-circulation of all the air, a considerable amount of heat has to be extracted during hot weather.

The advantage of cooling the air with a water spray over cooling it by direct contact with brine coils (bunker coils) is that the air readily takes up the temperature of the water in the spray while with the coils there must always be considerable temperature head to make the heat interchange effective. In other words, with the bunker coils the temperature of the brine must be considerably lower than that of the air to cause a rapid flow of heat from the air through the metal to the brine. The rate of heat transfer will also vary considerably as the entering air varies in temperature and humidity. It is difficult, therefore, to maintain close regulation with bunker coils.

If an abundant supply of very cold water, as from a deep well or a mountain stream, was available at small cost the refrigerating system could be dispensed with and the spray could be kept cool by a constant supply of fresh water.

Air cooling for human comfort calls for refrigerating machinery of large capacity but small range of temperature, with quiet running and as little danger as possible from leakage of the refrigerant. If the refrigerant be such that the pressure must be high there is greater danger of its leaking out and doing mischief. If on the other hand the pressure is below that of the atmosphere, air may leak into the system and contaminate the refrigerant. Ammonia is used more than any other refrigerant for large industrial plants, but it is very poisonous and it requires high pressures in the condenser so that any leakage becomes a menace to health as well as an expense. Carbon dioxide is harmless to health and it is used extensively as a refrigerant on ships where the escape of a poison gas would be particularly hazardous, but it requires very high pressures in the condenser and the compressor is expensive to maintain and operate. Sulphur dioxide is much used in household refrigerators and the required pressure is not as high as that of ammonia, but it is also poisonous.

To meet the special requirement of cooling for human comfort the machine shown in Fig. 10 has been developed. This comprises in one compact unit the compressor, the condenser, the evaporator, the brine cooler, the circulating pump for the refrigerant and the motor to supply the power. The refrigerant is diachloromethane and the pressure in the cycle ranges from 5″ of mercury below atmosphere in the condenser to 20″ below atmosphere in the evaporator. Any leakage therefore would be of air into the machine rather than leakage of the refrigerant into the room.

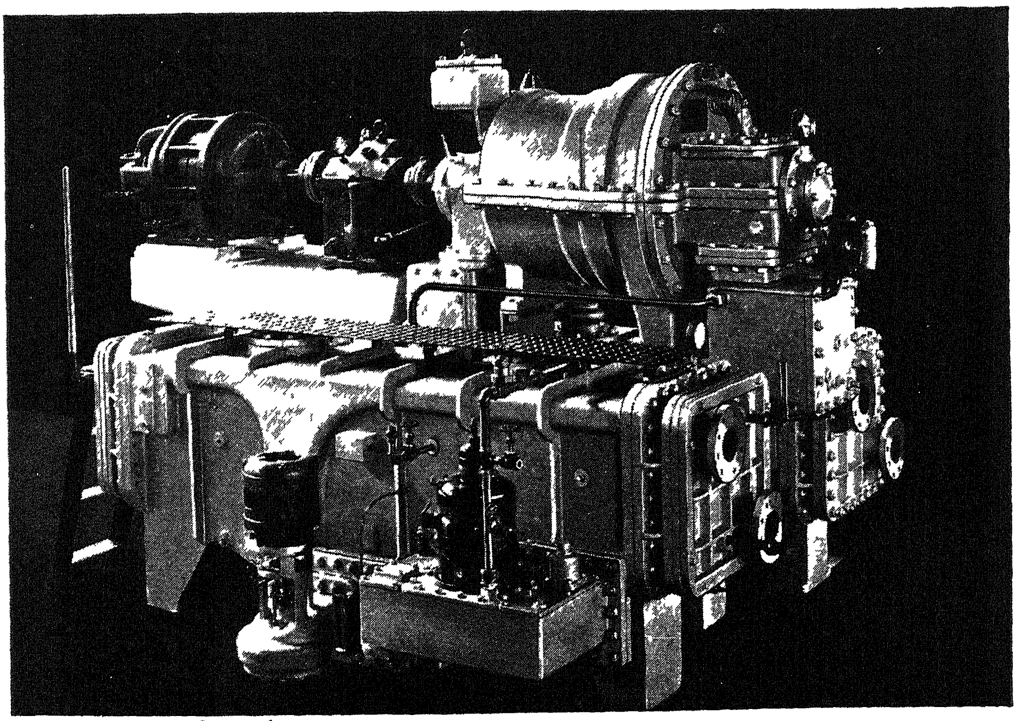
The problems of heating and ventilating are very broad. Each building has its own peculiar needs to be met and each requires special attention if the equipment is to be best adapted to the service. Some of the considerations are: are heating and cooling of principal importance; must the relative humidity remain constant; is air purification necessary and, if so, does the contamination of the air come from within or from without the building; is the natural leakage around windows and doors sufficient for ventilation.

Most states require, by law, that schoolrooms be provided with 30 cubic feet of fresh air per person per minute and that the rooms be kept at a temperature of 70° during the heating season. In handling some hygroscopic materials the relative humidity is of major importance and the matter of temperature is secondary. In some processes the dust and smoke of the surrounding air might spoil the product, and air entering such rooms must have been filtered or otherwise purified. Dust may result from operations within the room such as grinding, button making, chemical reactions, etc., in which cases removal of

the dust-laden or chemically contaminated air is of prime importance. Again the nature and size of the building may be such as to require special attention. The Merchandise Mart has only two small light and air shafts so that there is a vast amount of space which can be lighted and ventilated only by artificial means and this space would be worthless without lighting and ventilation. In this particular case 106 ventilating and exhaust fans force 2,200,000 cubic feet of air through the building per minute.

In the case of the R. H. Macy and Company building, which enjoys the distinction not only of being the largest store in New York, but also of being the first in the city to employ a system of cooling, the building was not only completed and in use, but the installation had to be made without interference with the regular business of the store. The cost of this equipment was $1,250,000 for conditioning the basement, street, second, third, and fourth floors only. The specifications called for a ten degree reduction in the air temperature during the hottest weather. The area is approximately 500,000 square feet.

The heat to be extracted includes: that generated by the lights and motors; that given off by a population estimated at 15,000, each of which would add from 300 to 400 heat units per hour; that transmitted through the walls, windows, and floors of the building; and that required to cool the outside air through ten degrees and condense the excess moisture. The estimated amount of heat to be extracted is 18,000,000 heat units (British Thermal Units) per hour. The first installation was made in 1929 for conditioning the basement and street floor, and in 1936 an additional installation was made for the second, third, and fourth floors.

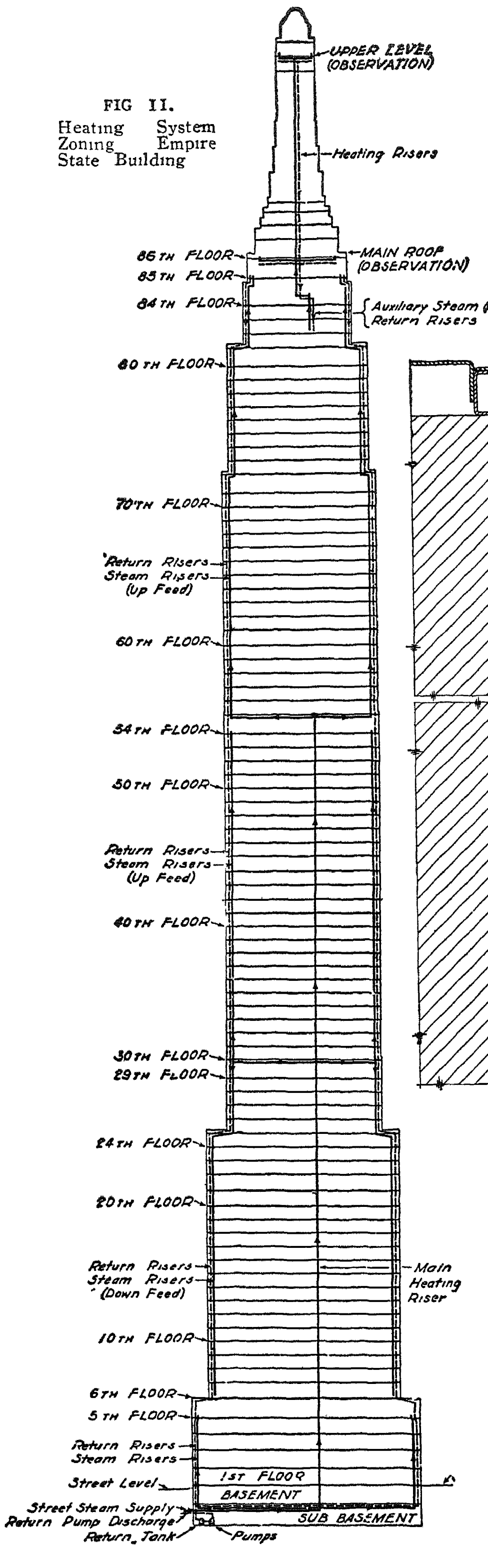


Courtesy Carrier Corporation

FIG. 10. REFRIGERATING UNIT FOR AIR COOLING.

The world-renowned Empire State Building, which is the tallest structure ever erected by the hand of man, presented a good many unusual problems for the heating system

FIG 11.
Heating System Zoning Empire State Building



because of its size and great height. The question of generating the required heat and power for the building was answered in the negative because a suitable chimney would occupy 350 square feet of floor space through each story making the sacrifice in rentable space more than offset the extra cost of purchasing heat and power.

For the purpose of heating, the building was divided vertically into four zones. The lower zone extends to and includes the

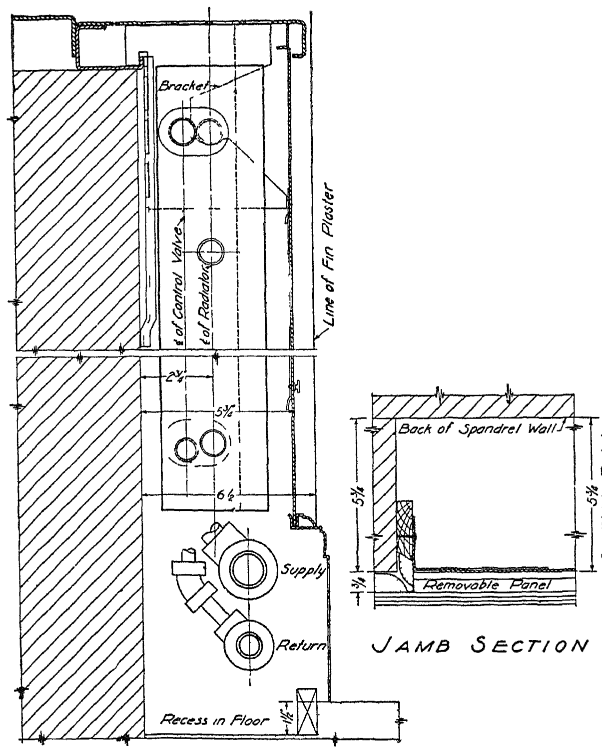


FIG. 12.
Typical Radiator Installation — Empire State Building.

5th floor For this zone the steam is distributed horizontally in the sub-basement and carried by numerous vertical risers and returns to all parts of the building within this zone. The steam for the remainder of the building is supplied through a 24-inch vertical main in the center and extending to the 29th floor. Here the steam is again distributed horizontally on the ceiling and the various risers for the floors between the 5th and the 29th are supplied by downward flow while the steam for the floors between

THE TALLEST BUILDING IN THE WORLD

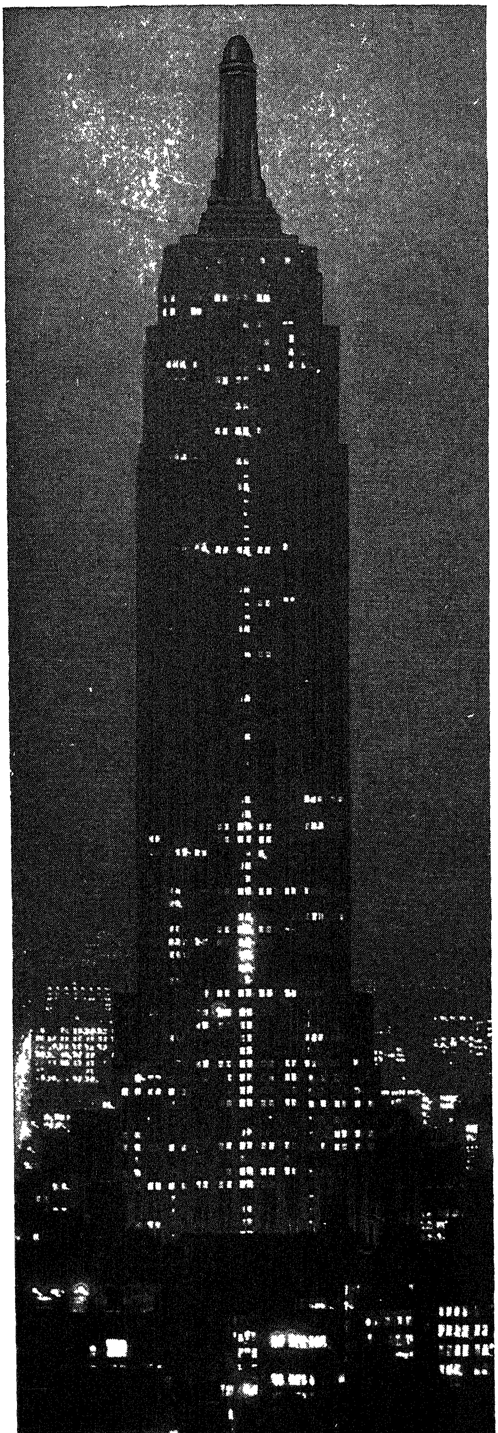


Photo Lewis W. Hine

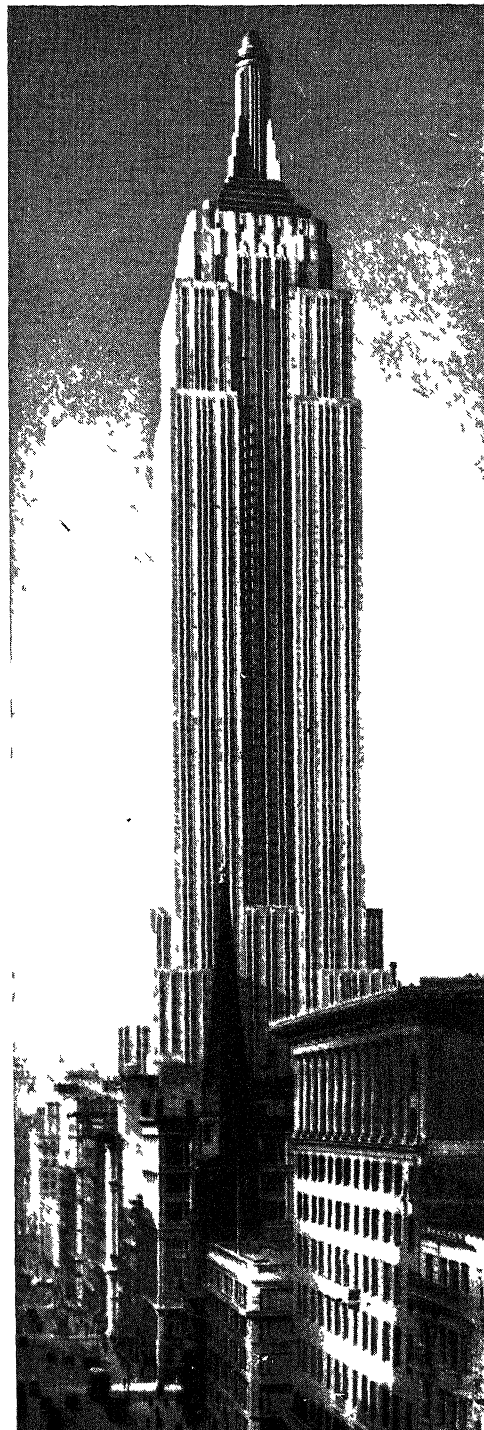
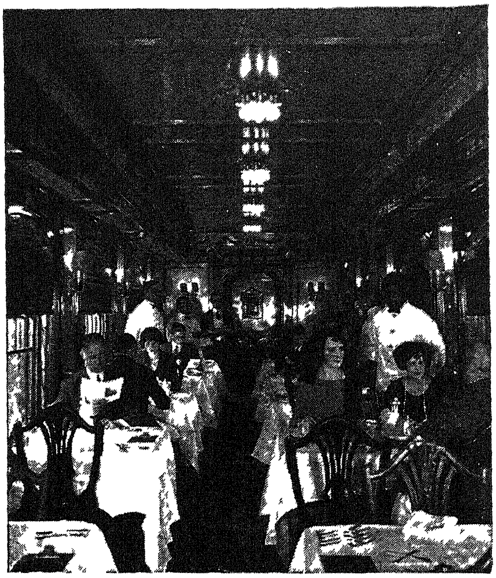


Photo Amemya

BY NIGHT FIG 13. EMPIRE STATE BUILDING BY DAY

World's tallest building; 85 stories above ground with 200 foot observation tower, total height 1,250 feet; cost $43 000,000; 7,000 radiators required for heating Shreve Lamb & Harmon, Architects.



Courtesy Engineering Publications Inc

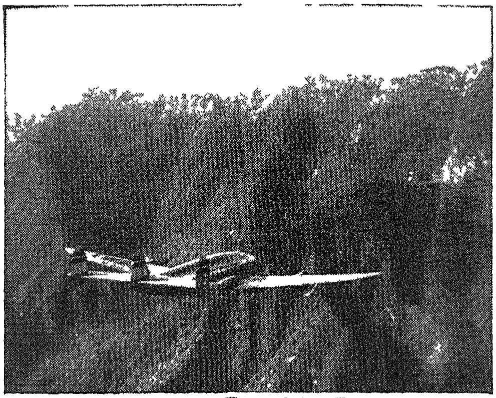
FIG. 14.
DINING CAR OF "THE COLUMBIAN."

the 29th and the 54th are supplied by the steam flowing upward. The main steam pipe is reduced in size at the 29th floor and then extends to the 54th floor where the steam is again distributed horizontally and vertical risers carry it to the remainder of the building. This system of zoning was used because a pipe of great size would have been necessary if all the steam had been carried by a single main. As it is each foot of this 24-inch main weighs over 100 pounds.

Mechanical ventilation was provided for the five lower stories at an estimated cost of 2 per cent of the average wage of the employees in that part of the building.

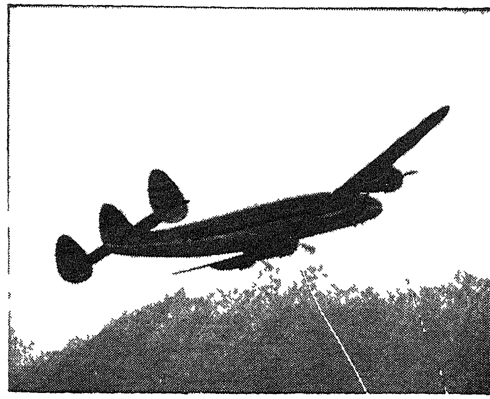
Another new feature of this building is that the windows are set nearly flush with the outside walls. This made it possible to place concealed radiators under the windows so that the radiators are flush with the inside walls as shown in Fig. 12.

A development that has been widely extended is the application of air conditioning to railroad trains. In the year 1930 the Baltimore and Ohio Railroad provided air conditioning for the dining car "Martha Washington." On May 24, 1931, they put into service a train, "The Columbian", running between New York and Washington with complete air conditioning equipment in each car. This was the first fully air conditioned train in the world. A second train thus equipped was put into service on July 20. Electric motors are now used to drive the refrigerating equipment on the trains.

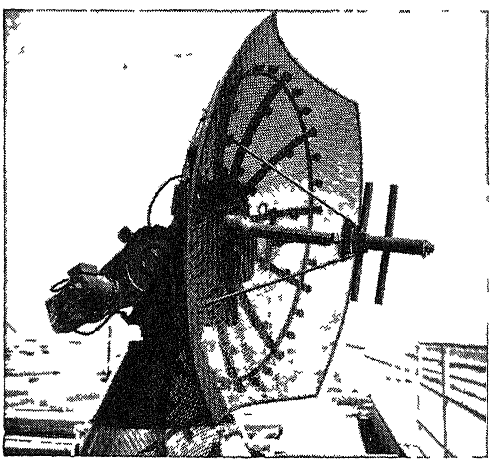


Upper photos, Hughes Aircraft Corp.

This plane is in grave danger; it is heading straight for a mountain that is obscured by fog.



The plane's radar set warns the pilot of his peril, he zooms upward and just clears the mountain



U S Navy

A close-up of sensitive radar equipment recording the exact position of planes above an airport.

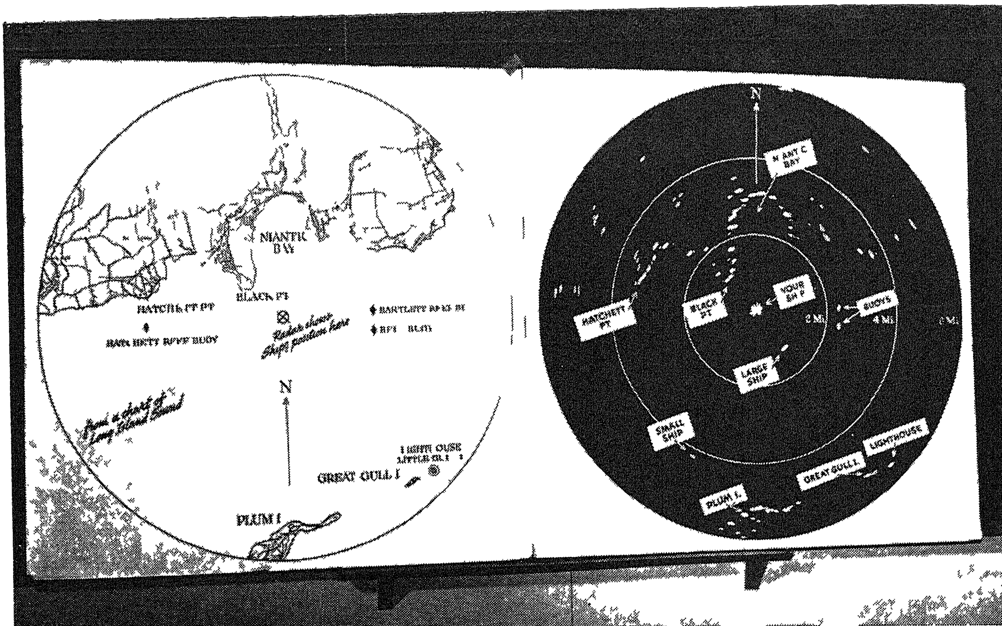
U. S. Navy

Approach controller bringing in planes by the radar-operated Ground Control Approach system. The operator keeps the planes at carefully selected levels until it is time for them to land.

RADAR TODAY

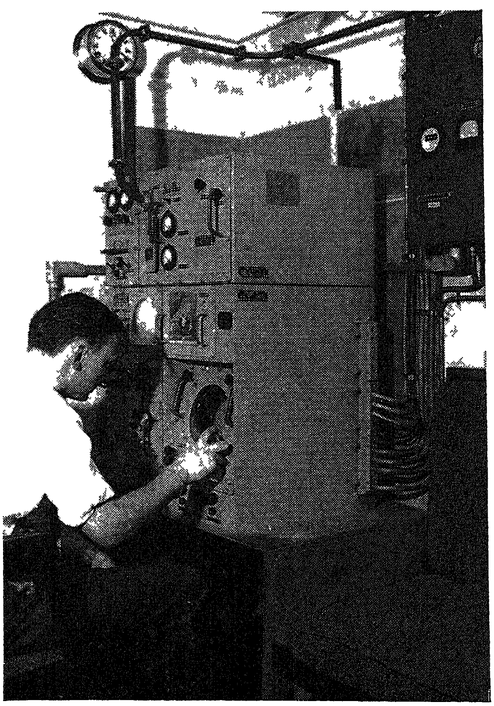
The name radar comes from the capitalized letters in the following words: RAdio Detection And Ranging. Radar, indeed, *ranges* far out into space and *detects* objects in its path. A beam of radio waves is sent out from an antenna at the speed of light (186,000 miles a second). If any object stands in the path of the beam, it is reflected or bounced back, likewise at the speed of light, to the sending point, and it hits a screen. As one beam after another hits various parts of the object and bounces back, we soon get a rough sketch of the object on the screen. The radio beams give us not only a sort of picture of the object but they also tell us how far away it is and the direction from which it comes.

Radar serves in many ways in war and peace. In time of war it warns of the coming of enemy planes; it detects the presence of submarines; it controls the aiming and firing of naval guns; it enables bombing planes to "see" enemy targets obscured by fog or smoke. In peacetime radar warns planes and ships of dangerous objects ahead; it guides planes to a safe landing (Ground Control Approach); it directs the flight of rockets sent hundreds of miles aloft. In these pages we show some modern uses of radar and of its offshoots, shoran and loran.



General Electric

These two charts show how the screen of a radar set shows the objects in its vicinity The view at the right is a photograph of the viewing screen as a training ship anchored one night off Niantic Bay, in Long Island Sound The map of the area, at the left, shows how faithfully the radar set has pictured the shore line, islands and buoys The sending point is always at the center of the screen

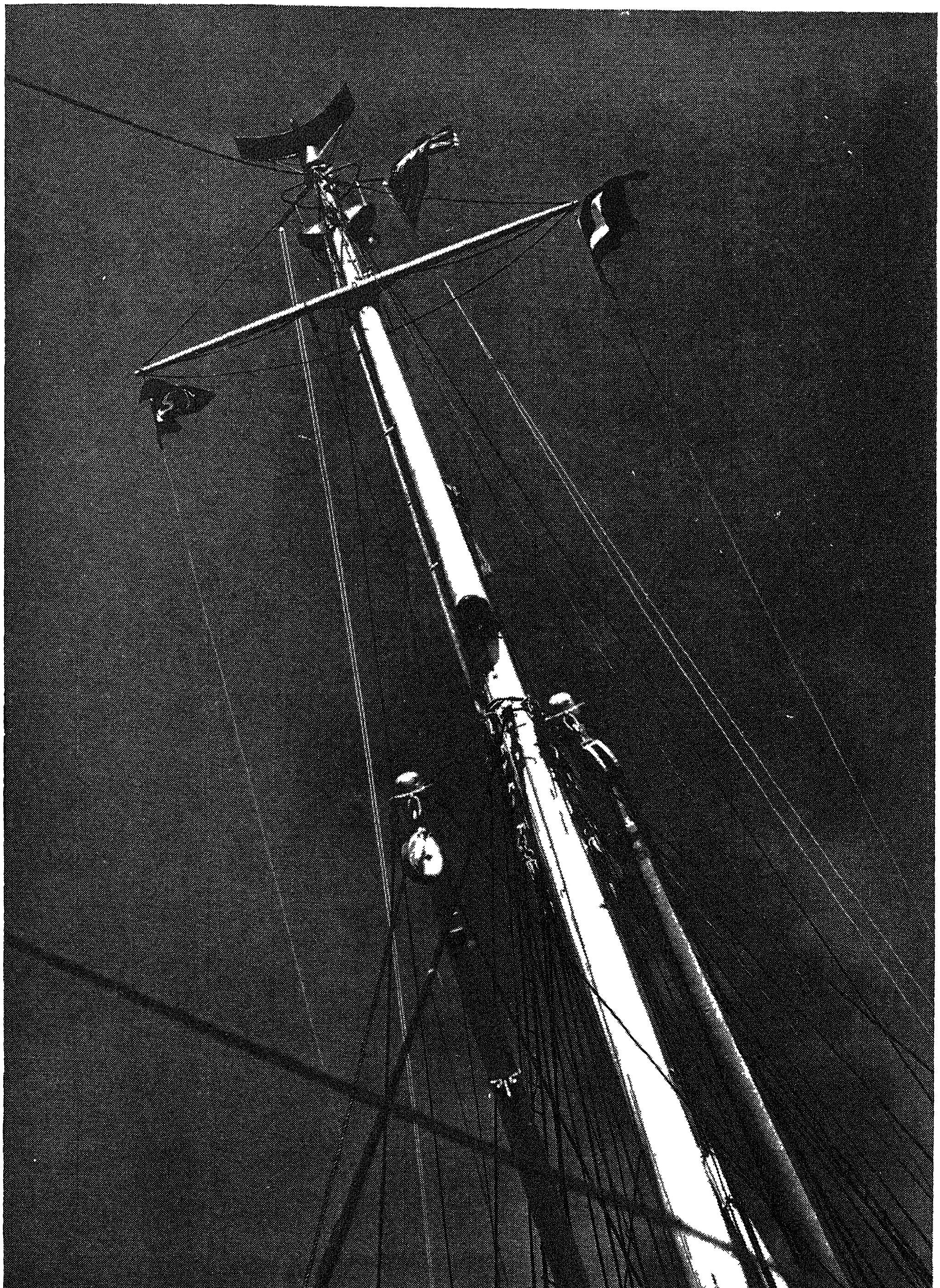


Imperial Oil Limited

An operator at the transmitter controls of a ship's radar set This equipment generates the powerful ultra-short radio waves that are broadcast by the steadily rotating antenna shown on the next page.

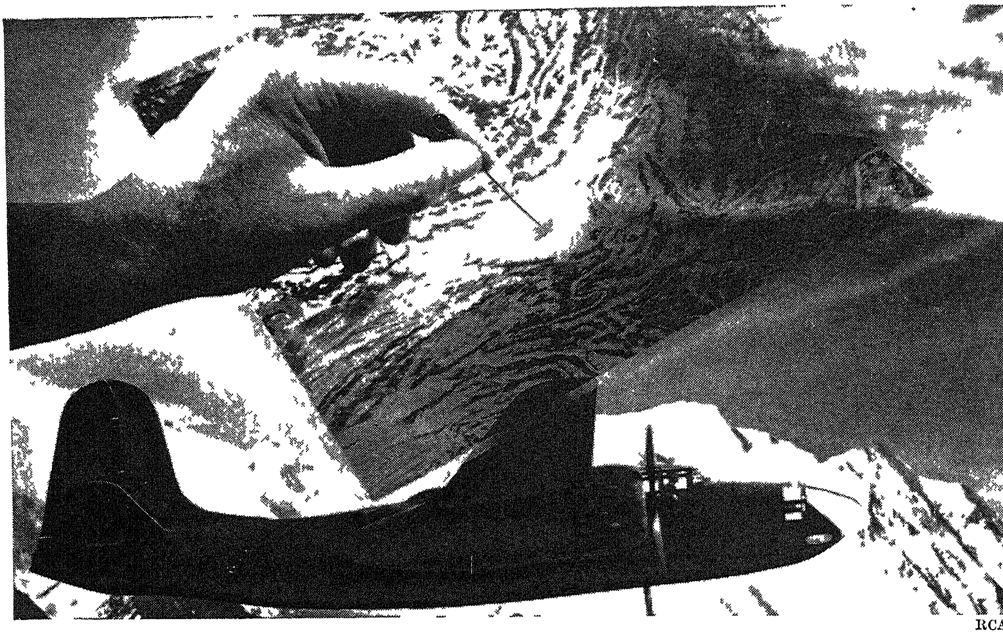
Raytheon photo

This executive officer is stationed at the viewing screen of his ship's radar set By carefully taking note of the objects shown in the viewing screen, the officer is able to chart the vessel's course.



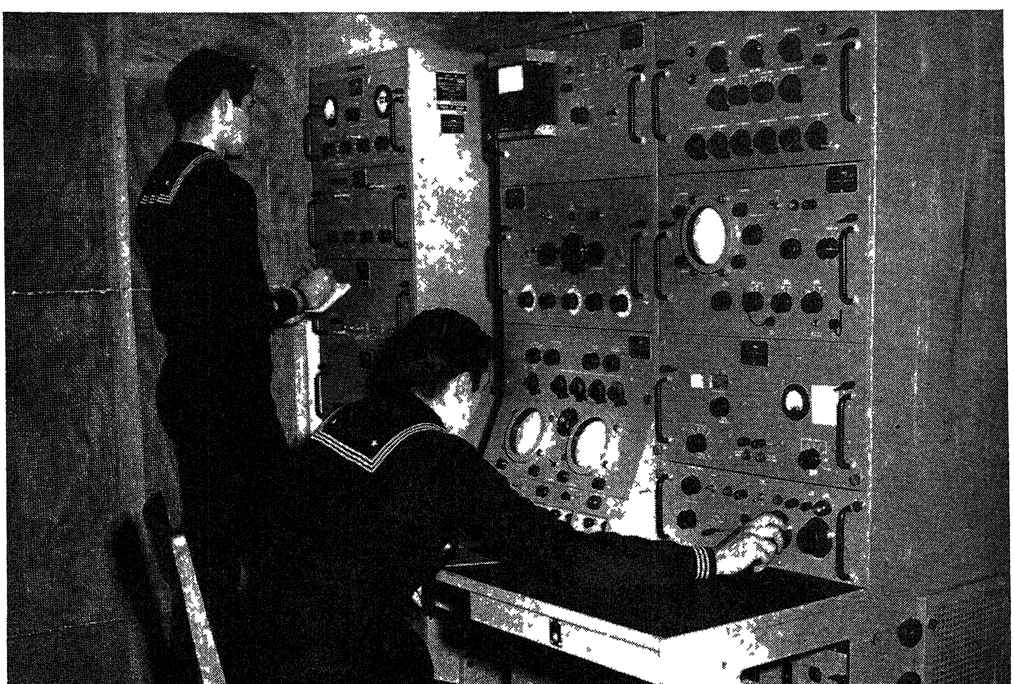
Raytheon photo

A passenger ship's radar antenna, perched atop the foremast, 103 feet above the deck. As the antenna rotates slowly, it continuously scans the surrounding waters with a succession of pencil-sharp radar beams. The antenna used in ordinary radio broadcasting sends out waves simultaneously in all directions. But in radar each beam must be sent out in a specific direction. Hence the radar antenna must be able to concentrate all its ultra-short wave energy into a single sharp beam. The antenna must rotate so that objects at every point of the compass may be scanned in turn by the radio beams.



RCA

Mapping an inaccessible region by means of shoran. Shoran was first used, and still serves, to locate the position of a ship within 200 miles of the shore; hence the name (SHOrt RANge navigation). The ship determines its position by sending out radar impulses to two stations on shore In measuring distances on land, the shoran set is installed on a plane; it also sends out signals to two stations.



U S. Coast Guard

A loran transmitting station. A ship using loran (LOng RANge navigation) has a loran receiver which receives the radio signals sent out from three transmitting stations on land—a "master station" and two "slave stations." The navigator receives signals from the master station and one of the slave stations; then from the master station and the other slave station. He can now compute his position.

OUR FOOTHOLD IN SPACE

The Planet We Know — Its Shape, Size, Density, Motion, Interior — How Is It Cooling, and Why?

THE WONDER OF THE AURORA BOREALIS

THE globe whereon we live is the third planet from the sun, from which it is distant about 93,000,000 miles. It is very nearly a smooth, round ball, but is slightly flattened at the poles, so that its diameter from pole to pole is rather less than the diameter through the equator. This difference is so small, however, that if the earth be represented by a globe twenty-four feet in diameter, the equatorial diameter would exceed the polar diameter by only about one inch. On the same scale, the highest mountains would be represented by elevations of not more than one-fifth of an inch. The globe is therefore very round and smooth.

The spherical shape of the earth is known in several ways. Thus in an eclipse of the moon the shadow cast by the earth on the moon's disk is always circular in outline. Circumnavigation of the globe affords another proof of the same fact. The roundness of the earth is even visible to the eye, when ships are seen descending over the horizon, and the hull is hidden while the masts are still clear, projecting over the sky-line. The degree of curvature may be roughly measured by a simple experiment. Thus if three pillars be erected in a straight line upon a plain, at distances of a mile apart, and the summits of the first and third be exactly levelled with the summit of the middle one, it is found, after due allowance is made for refraction, that a line from the summit of the first to that of the third passes about eight inches below the top of the middle pillar. That is to say, the summits of the three columns are on a curve; and from the degree of its curvature the diameter of the earth may be very accurately calculated.

By the measurement of the number of miles in one degree of arc at many different places on the earth's surface it is known that the mean diameter of the earth is about 7918 miles, the equatorial diameter being 7927 and the polar diameter 7900 miles.

The flattening at the poles, caused by the bulging out of the equatorial parts due to the rotation of the earth, may be estimated by comparing the length of two arcs of the meridian — one near the equator and the other near the pole. It is found that a degree of latitude near the pole is considerably longer than one near the equator, showing that in regions near the pole there is less curvature in the north and south direction than there is in the equatorial regions.

Another method of demonstrating the regular diminution of curvature from the equator to the poles is by estimating the force of gravity at different latitudes. In consequence of the northern and southern flattening of the globe, the surface of the earth in high latitudes is somewhat nearer to the center of gravity than it is in the tropics. Any object, therefore, weighed in the neighborhood of the poles is heavier than the same object weighed at the equator; and for the same reason a pendulum will vibrate more quickly in high latitudes than the same pendulum will vibrate when near the equator. The difference between the force of gravity at the poles and at the equator is found to be such that an object weighing 190 lbs at the equator will weigh 191 lbs. at the pole Measurements of the intensity of gravity have been made with great exactness by means of a pendulum, and the results obtained are corrected for the effects of centrifugal force at the equator.

Obviously, the centrifugal force of the earth's spinning increases greatly from high to low latitudes, and makes any object at the equator lighter than it would otherwise be.

The rotation of the earth on its own axis, by which any point on the equator is whirled round at the rate of nearly a thousand miles an hour, is shown in various ways. In the first place, as Copernicus reasoned, it is very much simpler to suppose that this globe itself rotates than to imagine that the immense host of celestial bodies are revolving round a stationary earth. Again, the telescope shows us that the sun, Mars, Jupiter, and other planets rotate, and it is only reasonable to believe that the earth also rotates. But experiments have proved the fact of this rotation beyond all possible doubt whatever.

The positive proofs of the rotation of the earth

For example, if a weight be dropped from a high tower, or down the shaft of a mine, its descent is not exactly vertical, but deviates somewhat towards the east. The reason is that the higher point, from which the falling object starts, being further from the earth's center than the lower point, at which the object comes to rest, the former is moving eastward, with the earth's rotation, more rapidly than the latter. The falling weight retains, during its fall, the eastward speed with which it started, and thus outstrips the point which was vertically below it, in the direction of the rotation of the earth. Foucault's celebrated experiment shows the earth's rotation in a very striking way. It was carried out for the first time in Paris in 1851 and created much interest and enthusiasm.

Foucault suspended a heavy iron ball from the dome of the Pantheon by means of a wire over two hundred feet long. Under the pendulum a circular rail about twelve feet across was placed with a ridge of sand built up on it. The pendulum having been set going in an absolutely true swing, made little marks on opposite sides of the ring of sand. But at each swing of the pendulum the new mark was made at a place slightly removed from the last, as if the plane in which the pendulum swung were moving very slowly round in the direction of the hands of a clock. The fact was that the pendulum retained its original plane of movement, but the floor, with its ring of sand, was slowly rotating with the rotation of the earth.

How the density of the earth's mass is determined

If suspended at the North Pole, a pendulum of this kind would appear to make one complete rotation of its plane of movement in twenty-four hours, and the rotation would be clockwise. At the South Pole the rotation would take the same period of time, but its direction would be counter-clockwise. At the equator there would be no such rotation. At Paris, the rotation was clockwise because in the northern hemisphere, and the pendulum moved round the circle at the rate of one complete rotation in thirty-two hours. An experiment which is essentially identical with the above has been made with the gyrostat, with the same results.

The density of the earth is slightly more than five times and one-half the density of water. That is to say, the mass, or gravitative force, of the earth exceeds in that proportion the mass of a sphere of water of the same dimensions. The determination of the earth's mass is a difficult matter, which has been attempted by several ingenious experiments. By estimating as nearly as possible the mass of a mountain, and measuring its attraction for a ball of lead of known weight suspended on a plumb-line, the mass of the earth, whose attraction for the leaden ball is known from the weight of the latter, may be readily calculated.

Or, having once estimated the mass of the mountain, it is possible to measure the force of gravity at the mountain top and on the plain below, and to make the required calculation from the difference between the force of gravity in these two situations. Or the gravitative force of a heavy metal sphere upon a smaller ball may be measured, and compared with the gravitative force of the earth upon the same object.

The elliptical shape of the earth's orbit and some of its effects

The orbit of the earth is an ellipse, lying in the plane of the ecliptic. The plane of the orbit passes through the sun, which is situated not in the center of the ellipse but at one of its foci. An ellipse is a curve consisting of points which are such that the sum of the distances of each point from two fixed points is always the same. Thus, if two pins are stuck in a board, and a ring of string is laid on the board inclosing both pins, and a pencil is made to travel round, stretching the string as far outward as it will go, the pencil will draw an ellipse, of which each pin will represent a focus. Plainly, a circle is a special case of an ellipse, in which the two foci coincide. As different points on an ellipse are unequally distant from a focus, the earth during part of the year is nearer to the sun than it is at another time of year. The point of the orbit at which the earth is nearest to the sun is called perihelion, and the point at which it is furthest is called aphelion. At perihelion the apparent diameter of the sun is, of course, larger than it is at aphelion; but as the eccentricity of the orbit is small, this difference in apparent diameter is so slight as not to be observed except by careful instrumental measurement.

It has long been a matter of dispute whether the interior of the earth is on the whole in the solid or the fluid state; whether it is viscous or elastic. We know that its heat must be very great, from the rapidity with which the temperature rises as we descend in mines. The density also is great, because the average density of the materials of the crust is considerably less than the density of the earth taken as a whole.

The argument in favor of the solidity of the earth

The heat is far more than sufficient to melt the most obdurate rocks, but the pressure also is enormous, and may be sufficient to prevent the molten condition. From the resistance which the solid earth, as distinguished from the oceans, opposes to the tide-raising power of moon and sun, Lord Kelvin concluded that the earth is solid to the center, and has a rigidity greater than that of steel. This conclusion was necessarily based on somewhat indeterminate data and did not definitely settle the question; but in 1913 Michelson and Gale, of the University of Chicago, carried out at the Yerkes Observatory an extensive and very accurate series of measurements of the actual tides raised in long horizontal pipes half filled with water. By computing the theoretical range which these tides would have were the earth perfectly solid and unyielding to tidal strain, and comparing this range with the tides actually observed, it was possible to determine with a high degree of accuracy the amount by which the earth itself yields to the tidal strains produced in it by the action of the sun and moon. This investigation confirmed Lord Kelvin's conclusion and showed that the earth is not liquid but solid throughout; that it is not viscous in its interior but highly elastic and as rigid as a sphere of solid steel of the same dimensions.

The two stages of planetary life-history required by astronomy

Such is the present condition of the earth: as to its past history, astronomy teaches as highly probable the theory that the earth was once a globe of incandescent gas, such as the sun now is, and that it slowly cooled, becoming first liquid and then solid.

This long period in the planet's life-history, during which it loses heat continuously, may be divided, according to Lowell's vivid description, into two parts, which he named respectively the "self-sustained stage" and the "sun-sustained stage". The huge outer planets Jupiter and Saturn, with their permanent envelops of cloud, are in the former and younger stage; our own planet, with often cloudless skies and its surface heated by the sun, is in the latter or older stage. The self-sustained stage comes to an end and gives place to the sun-sustained stage as soon as a planet's mantle of cloud is broken through; that is to say, as soon as cooling has proceeded so far that the planet's and surface heat is no longer sufficient to vaporize water.

There was doubtless a time when the earth's surface was at a temperature far exceeding that of boiling water, and when consequently there were neither oceans, lakes, nor rivers, but the world's whole store of water was suspended in the atmosphere, at first in the form of uncombined oxygen and hydrogen, then in the form of water-vapor, and finally, when the atmosphere was cool enough, in the form of clouds. This early absence of water from the earth's surface is corroborated by the fact that in none of the earlier geological formations is there found any trace of the work of water.

The condition of the earth when it was cooling rapidly

In the course of ages the surface of the earth's crust cooled to a temperature somewhat less than that of boiling water; and as soon as it did so the depressions in the surface must have begun to fill with nearly boiling oceans, throwing up enormous volumes of vapor, which was condensed into a murky envelope of cloud over the whole surface of the globe. The earth continued to cool, but through the lapse of vast periods it still remained shut off from the sun by its cloud mantle. The heat at its surface was almost exclusively heat from its own interior, and not heat from the sun, since this was reflected and radiated back into space by the cloud mantle. There were therefore no differences of seasons throughout the year, nor any differences of climate from pole to equator. Everywhere and always there was the same moist, gloomy heat. The whole world was like a dim hothouse, and it may be that during this period there flourished that stupendous vegetation of gigantic tree-ferns and other plants constituting the primal forests from which our coal measures were formed.

With further loss of heat, our planet passed at length from this self-sustained stage to the sun-sustained stage. As soon as those steamy seas had so far cooled as no longer to keep up the dense, universal mantle of cloud, the earth became subject to two influences unknown to it before — the radiant heat of the sun and the nocturnal chill of outer space. Heat from without was able to enter, but inner heat was also enabled to escape. Gradually, as the earth's seclusion was by degrees broken down, the seasons of the year were marked out from one another, and the various climates were differentiated in zones about the globe. The trees began to show the passage of the years by annual rings of growth in their wood, for hitherto they had grown continuously without recognition of seasons. Later, with increasing difference in the seasons, they began to shed their leaves in autumn and to remain leafless until the spring.

Reasons for supposing that the earth is losing its supply of water

The earth's escape from the self-sustained stage into the sun-sustained stage seems to have been marked also by the first appearance of land animals, in addition to the marine fauna previously existing.

To judge by what we know of the moon and of the planet Mars, the future history of our planet will be a gradual process of desiccation. The earth's store of water is passing away into space in the form of vapor; and Lowell held that the remarkable extension of desert areas within historic times is associated with this diminution in the total supply of water. The northern parts of Africa were formerly well populated, but are now desert; the ruins amid the arid regions of North America testify that these areas were once fit for habitation; the great inland seas of the world are slowly drying up; and there is reason to believe that the level of the ocean itself is sinking.

Finally, if the fate of the earth is to be like that of Mercury, it will at last rotate so slowly on its axis that one side will always be turned toward the sun. That side will be burned in the heat of eternal day, and the other, cold and dark.

The mysterious natural phenomenon of the northern lights

The northern lights, or aurora borealis, are now known to be electro-magnetic in nature. They may usually be seen in the general direction of the earth's magnetic poles, though their origin is on the sun.

It is called either aurora borealis or aurora australis according as it occurs in the northern or in the southern hemisphere. Auroras are phenomena of exceedingly varied appearance and brightness, and are sometimes of great splendor. They shine out suddenly in the heavens, flashing and darting, and execute the strangest, rapid movements and swift changes in form and intensity. We know now that the aurora is caused by sun-spot activity on our sun. Until recently this was not understood. In some parts, chiefly in the Arctic regions, auroras are of frequent occurrence but of inconsiderable extent; others again, though occurring more rarely, are of enormous extent, and are visible over the greater part of both hemispheres.

The recurrence of these displays seems to show some degree of regularity. Various degrees of frequency have been remarked in certain well-defined zones, increasing from the tropics, where no auroras occur, to a region of maximum frequency which constitutes a small, irregular oval, round a point which is known as the auroral Pole, and is situated at about 81° N. 70° W. This line of maximum frequency passes by the North Cape, the northern extremity of Nova Zembla, the northeastern extremity of Siberia, Hudson Bay and Labrador, and well to the south of Greenland and Iceland. Within this line, towards the North Pole, the frequency again diminishes. Concentric curves of the same oval form mark the diminishing degrees of frequency south of the maximum line.

The different forms assumed by the aurora borealis, and its local frequency

From the shape of the curve it is obvious that auroras are more frequent in America than in the same latitude in Europe. The numbers of auroras recorded give approximate averages of 1 in 10 years for the south of Spain, 5 a year in the north of France, 6 in London, 30 in the north of Ireland, 60 in the northern United States, 80 in the greater part of Canada and 100 in the Faroe Islands, along the northern Siberian coast, and in the south of Hudson Bay and Labrador. These numbers refer to those visible to the unaided eye: but V. M. Slipher of the Lowell Observatory has secured definite spectroscopic evidence of faint auroras even when none was visible to the eye, and it is probable that these faint auroras are continuous in higher latitudes.

The appearance of the aurora varies from that of a mere faintly diffused light to very definite and resplendent forms such as those which are known as crowns or draperies. Again, the faint illumination varies much in extent and brightness, covering sometimes the whole sky, sometimes quite small portions of it and sometimes glimmering along the edge of the horizon. The light is in these cases usually dimly white, not unlike that of the Milky Way, or may resemble thin, luminous tissues spread out in the sky. Auroras of this type can easily escape observation, as they may be taken for the dying sunset rays or the light of the coming dawn, or may be nearly obliterated by other illumination, such as moonlight or the glare from cities.

Next we remark a somewhat brighter and more definite form of the aurora, wherein it resembles the clouds known as cirrus — that is to say, the delicate, fibrous, feathery clouds. Indeed, the two phenomena are sometimes indistinguishable, and sometimes occur together or replace one another. Like the aurora, cirrus clouds are often arranged in more or less circular belts, with an apparent convergence towards a definite point in the horizon. Patches of auroral light, less delicate in form than the feathery cloud-like lights, also occur; and these are sometimes subject to strange fluctuations, the light shining brilliantly for a moment while contracting in area, and then resuming its more diffuse and less brilliant appearance, very much as if a searchlight were being thrown across the sky.

But the most striking auroras take much more definite and brilliant forms than these. The grander auroras are again exceedingly varied, but the more usual forms are arcs or rays of light, and the magnificent appearances known as crowns and draperies. Auroral arcs are generally more or less circular, but they are sometimes elliptical.

They may be homogeneous curves of light, or curves consisting of rays perpendicular, or nearly, to the direction of the arc. The rays which make up the arc are usually bright and well defined along their lower edge, but fainter at their upper extremity, often fading imperceptibly into the sky. Two or more arcs, usually concentric, are not uncommon, especially when the arcs consist of rays; and sometimes four or five, and even as many as nine, arcs have been seen at one time

The rays which form the arcs are usually short, but occasionally reach a great length, stretching upward toward the zenith. Similar rays may exist alone or in groups forming columns, which are subject to equally rapid and varied movements. These rays are often of considerable brilliancy, sometimes sufficient to produce reflections in water or snow. They may be seen to shoot upwards, lengthening themselves rapidly, or to move swiftly in the horizontal direction; sometimes they

THE ADVANCE OF THE DESERT — THE SAND-SWEPT RUINS OF AN EGYPTIAN FORTRESS

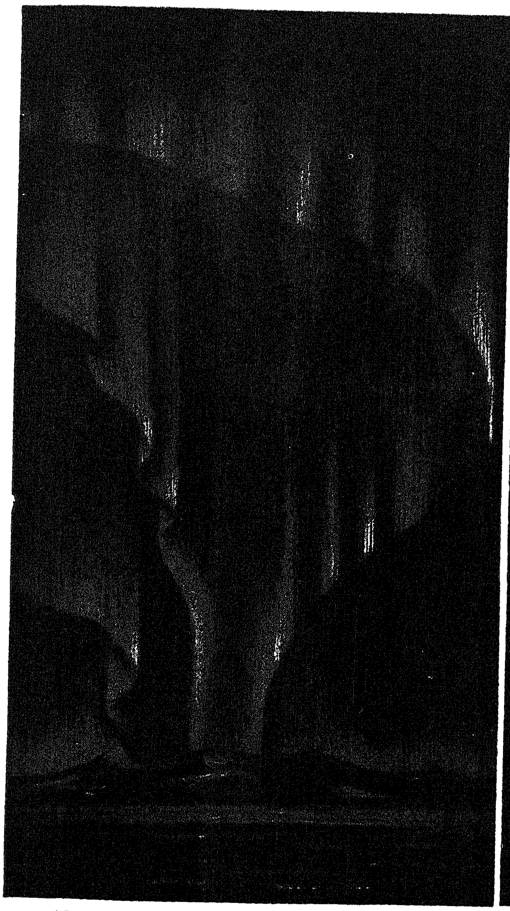
This old fortress, Dareheib Castle, was the treasury as well as a barracks, situated in a once fertile plain, to guard the mines of the Egyptian government hundreds of years ago

The light often seems to pulsate along these arcs, passing from ray to ray with great swiftness, and producing an undulatory effect. These rayed arcs are subject to many rapid movements and changes; they move upwards and downwards, vanish and reappear in part or in whole, lose their rayed structure, and for a time become homogeneous bands, and even perform more complex movements than these; thus, the feet of the arc may move in opposite directions, while the vertex remains stationary, as if the entire arc were moving round a vertical axis.

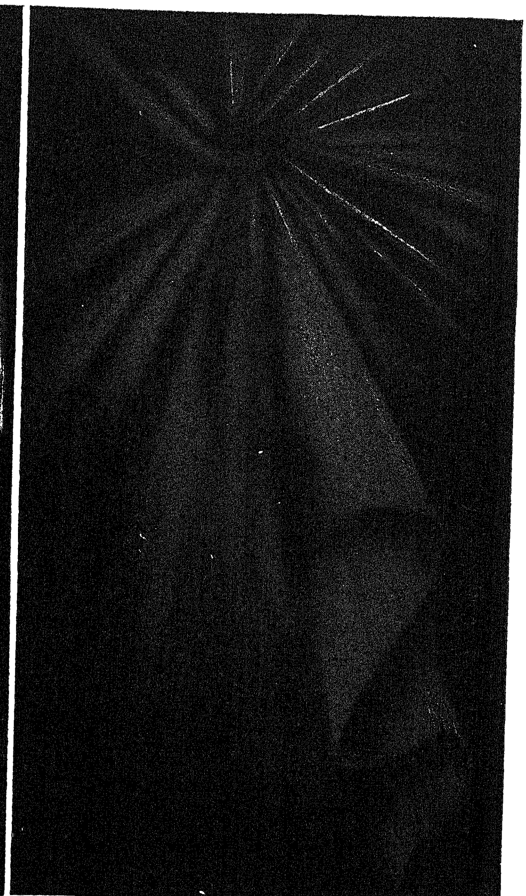
become fused together to form a fragment of an arc; sometimes there are many separate rays, all converging towards a single point Some of the quick movements of these rays are peculiarly characteristic of the aurora, and have been noticed from the earliest times; thus the ray, remaining in itself of the same size, may leap with an up-and-down movement, an appearance known in Canada as marionettes and in the Shetland Isles as merry dancers Probably the aurora borealis gave rise to a number of ancient stories of armies fighting in the skies.

The display known as the crown, or glory, is produced when the rays, packed closely together, converge upon a single point, generally the magnetic zenith. The effect is often one of great magnificence; the rays may form a complete circle and sweep downwards to near the horizon, producing the dome-like effect called by old writers a tent or pavilion. Sometimes the top or center of the dome is wanting, and the auroral rays then form an immense luminous band around the horizon; and sometimes one side is wanting, and the rays are then said to form a wreath. This crown type of aurora is generally confined to high latitudes.

Quite the most resplendent auroras are those known as draperies, the rays being in this case strongly developed and very close together. They are not grouped round a common center, but join together in less regular form, presenting the appearance of wide bands of drapery, undulating, or as if folded many times upon itself, like a streamer of some light fabric fluttering in the wind. Auroras of this kind, like all others, are usually much brighter and better defined along their lower edge, the light becoming fainter above and merging indistinguishably into the sky. The colors are often superb.



AURORAL STREAMERS IN THE ANTARCTIC



AURORAL CORONA, LOOKING TOWARDS THE ZENITH

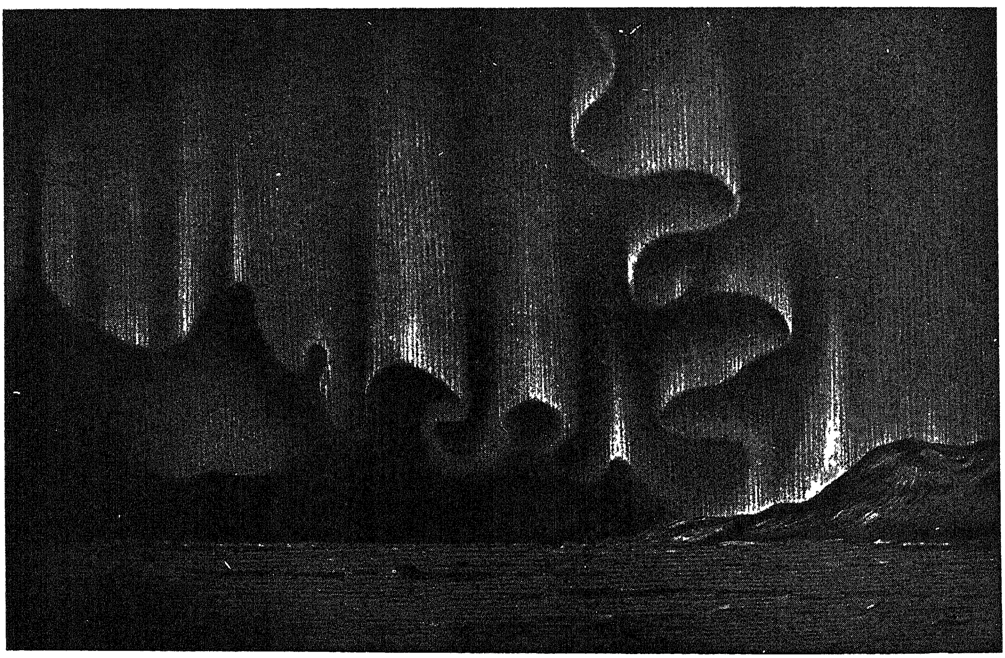
The aurora varies greatly in color, although it is perhaps more often white or greenish or yellowish white in hue. In the great displays of draped and curtain auroras we often see brilliant rose tinged with violet. The greater part is still of yellowish-white, but sometimes above this

there is a green tinge, not usually so bright, however, as the red below. When the whole is in movement, like a huge flag floating in the wind, the effect is magnificent. The crown aurora also at times takes on these vivid red and green tints, and then forms one of the most glorious manifestations of the aurora.

This grouping of colors — red, yellowish-white and green — is also found in isolated rays. If the rays move downward the colors become intensified to great brilliance, but when they move upward the colors grow correspondingly fainter.

considered as the characteristic auroral line. It is in the yellow-green region of the spectrum, and is nearly, if not actually, coincident with a prominent line in the spectrum of krypton, an atmospheric element discovered by Sir William Ramsay. Two other lines are also prominent in the auroral spectrum.

The aurora is at times accompanied by a peculiar noise, described by Curtis as "faint swishing, crackling sounds" and by others as not unlike the rustling of silk; for the most part, however, these displays are inaudible to the ordinary observer.



AURORAL CURTAINS THAT CHANGE THEIR BEAUTY EVERY PASSING MOMENT

The brightness of the auroral light varies considerably over the illuminated area, and frequently from moment to moment. It is difficult to give any accurate estimate of its brilliancy, but it is fairly certain that it is much less than that of moonlight. Observers in the Far North have indeed compared the light of the aurora to that of the moon as an electric light to that of a common gas-jet, but brilliant displays of that kind must be very rare.

The spectrum of the auroral light consists of bright lines, showing that the source of light is gaseous. One of these lines is so dominant that it has come to be

The rapid movements of many auroras, and the merely local character of many more, have made it very difficult to measure the height at which these northern lights are displayed above the earth. All the evidence, however, goes to show that the great auroras of wide extent are at a great height above the surface of the earth. Recently it has been proved that many auroral displays occur at heights of four or five or even six hundred miles (the limit of the atmosphere) above the earth's surface. They are believed to occur within a range from forty miles to six hundred miles above us, although the

average height is probably about sixty miles. Observation of the aurora and determination of its height has added to our knowledge of the earth's atmosphere.

These high auroras have on several occasions been observed over the whole of Europe, the greater part of Asia and in Australia, South Africa and other regions of the South, simultaneously. Indeed, it is probable that at such times the whole earth, with the exception of an equatorial zone about forty degrees in width, is enveloped in the light of aurora borealis and australis. Such were the auroras of February 4, 1872, and September 1, 1859.

Local auroras, on the other hand, are much lower, being sometimes within a hundred yards of sea level, and often low enough to illumine the under side of clouds, or to be interposed between the observer and distant hills. These low auroras may be of complicated form, such as the draperies and rayed arcs described above. They are visible, as a rule, within only a very limited radius, and are of frequent occurrence in high latitudes. It is believed that this wide difference in height and extent marks a real difference in the character of two distinct phenomena, which are grouped under the common name of auroras; and this belief is strengthened by the fact that the great auroras, high above the earth, and visible in both hemispheres, are always accompanied by magnetic disturbances, while the low and local auroras have no relation to magnetic storms. Moreover, a correspondence between the periods of greatest sun-spot activity and those of greatest auroral frequency has been made out.

A PHOTOGRAPH OF THE NORTHERN LIGHTS — THE WESTERN END OF A MAGNIFICENT ARC THAT STRETCHED ACROSS THE SKY AT BOSEKOP, IN NORWAY, LIKE A BLUISH-WHITE MILKY WAY

Scientists believe now that the aurora gives no evidence of occurring seasonally or at special times of night. Its appearance cannot be foretold with any degree of accuracy. Since it is now certain that the aurora is associated with sunspots, it is best to watch for the aurora when there are many sunspots.

Some observers of the aurora have maintained steadfastly that there is a peculiar odor, almost like that of ozone, when the aurora is observed, particularly in the far north. Scientists, however, do not put much credence in this report.

The aurora is certainly electro-magnetic. During an expedition in high latitudes a prodigious draped aurora was seen to approach from the south until it passed directly overhead, and swept away towards the northern horizon. In exact correspondence with the movement of the aurora the magnetic needle deviated first to the west, oscillated as the aurora passed overhead, and then deviated to the east. This coincidence was often observed. These are exactly the movements of the needle which would have been produced if electric currents directed upwards from the ground had been moving in the place of the aurora.

Another phenomenon with which the greater auroras are intimately related is telluric currents. These are currents which arise spontaneously from time to time in telegraph and telephone wires, or any other insulated wires which communicate at both ends with the earth. Auroras are often accompanied by telluric currents of such magnitude as to interrupt the transmission of telegraphic messages.

The small and low auroras show no relation to magnetic disturbances, but appear to be related to certain weather conditions, especially, as we have seen, to cirrus clouds, but also to the existence of ice, and to high barometric pressure. The subject is, however, still very obscure.

Theories of the nature and causes of the aurora have been very various, and we need not spend a great deal of time over them. Astronomers now agree that the aurora is caused by tiny electro-magnetic particles from sunspots. Auroras of the higher atmosphere may be closely simulated by the effect of electrical discharges on Geissler's tubes, which contain highly rarefied air; the air within the tubes becomes luminous in immediate response to a sudden change in the electric field surrounding them.

The aurora is regarded by Edlund as being caused by what is known as unipolar induction, by which electric currents are produced in any sheath-like metallic body which revolves about a magnet at its center. The earth is a body of this kind, having two poles to the central magnet, namely the magnetic poles, which nearly but not exactly, correspond with the poles of its axis. Now, according to the laws of unipolar induction, a molecule charged with positive electricity is subject at the earth's surface to the action of two forces — one driving it upwards directly away from the earth, and the other drawing it towards the nearest pole. The vertical force is at its maximum at the equator, and diminishes to nothing at the poles, but the horizontal force drawing the molecules towards the poles is at its maximum in middle latitudes, becoming nothing both at equator and poles.

The result is that molecules charged with positive electricity are driven upwards, especially in equatorial regions, so that electricity accumulates in the upper atmosphere. In the tropics this accumulated electricity is discharged principally by means of the frequent and violent thunderstorms which are characteristic of those regions. But as much of the electricity rises to great height in extremely rarefied air, it flows easily towards the nearest pole, obeying the force which draws it in that direction; and most of it is discharged on the way in the form of auroras.

C. W. Gartlein, Cornell University physicist, in the 1946 edition of GROLIER ENCYCLOPEDIA says: "The spectrograph reveals that the auroral light is produced by atoms of oxygen and atoms and molecules of nitrogen. The upper atmosphere is at times bombarded with unusual numbers of charged particles from the sun giving rise to aurora, and to magnetic, earth current, and radio disturbances. The aurora tends to recur at intervals of twenty-seven days and increases in frequency approximately as the number of sunspots increases. The magnetism of the earth controls the aurora and without it the aurora could not be formed since the particles would not be bent into the dark side of the earth. The rays are along the lines of force of the earth's field."

WATER STORES IN SPRINGS

Springs of All Kinds — Intermittent, Submarine, Fresh, Hot and Mineral, and the Wells that Give them Freedom

THE RESURRECTION OF THE WATERS

SOME rivers, as we have said, originate in springs. But how do springs themselves originate? To the untutored, unscientific mind there is something mysterious and miraculous about water gushing from a rock or bubbling out of a mossy hollow; and to the imaginative Greeks the springs were full of poetical suggestion. The springs of Hippocrene and Castalia still water Parnassus, and still the Grecian fountains sing of old stories. "One is the charming Acis, escaping from the lava rocks under which the Cyclops wished to overwhelm him; another is the nymph Arethusa swimming under the sea so as not to mingle her blue water with the troubled wave; another, again, is the virgin Cayne, bathing the flowers which she once gathered to weave a coronet for Proserpine." Even in comparatively recent days strange theories of springs were in vogue; it was long believed that springs were air condensed into water in subterranean chambers, or sea vapors condensed in cold caves. Now all mystery has gone; now we know that a spring is simply a resurrection of subterranean rain-water.

Let us look for a moment at the manner of this resurrection. As we have already seen, the greater part of the rainfall is not collected by the rivers but soaks into the soil. The depth to which the rain penetrates depends both on the amount of rain and on the nature of the soil. Clay and compact loam are very impermeable to water, whereas sandy and gravelly soils are very permeable.

Vegetation assists the permeation of water, and some peat-mosses contain enormous quantities of water. The big peat-bogs of Ireland and our own cypress swamps, covering thousands of acres, must contain millions of tons of water. Where the soil consists of hard rock, rain penetrates with more difficulty; but even the hardest rocks, such as granite, are permeable to some extent; and the more porous rocks, such as limestone and sandstone, imbibe rain-water like a sponge. Stone taken fresh from a quarry is usually found to hold water — the so-called quarry-water. Necessarily, when rocks have imbibed all the water they can hold, they are no longer permeable, and rain runs off them as off a plate.

Now, suppose we have a layer of gravel resting on a layer of clay, what will happen? The rain will run through the permeable gravel till it reaches the almost impermeable clay. On the top of the clay the water will collect; and if, as is usually the case, the surface of the clay slopes or *dips* in a definite direction, then the water will run down the surface of the clay in this direction, until eventually it may find an outlet into the air, when it will issue as a fountain or spring. If, on the other hand, the clay should form a large concave surface, the water will gradually fill the concavity like a basin, and, pouring over its edges at one point or another, may find exit from the ground. Or there may be a crack or fissure in the overlying permeable gravelly soil, and the water, as it rises in the saucer, may rise into this fissure.

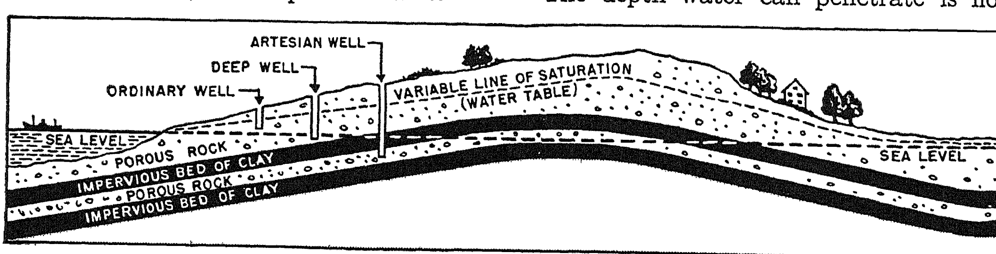
In other cases the water may take a labyrinthine course in various directions before it finds escape. Not uncommonly the water takes a V course, running down one arm of a V-shaped fissure and being forced up the other arm to its exit. In such a case the arm in which the water descends will be longer than the arm of exit; and the pressure at which the water rises will depend chiefly on the weight of the water in the longer arm compared with the weight of the water in the shorter. In many cases, springs of this kind go very deep, so deep that they reach the hot, deep rock regions, and, getting heated there, issue as thermal waters. Of this nature are the hot springs of Bath, Baden, Carlsbad, Wiesbaden, Baden-Baden, and Aix-la-Chapelle, in Europe, San Bernardino in California, Las Vegas in New Mexico, and many others, and, as a general rule, the hotter the water, the deeper its source.

There are certain very interesting springs known as "intermittent", that flow freely for a certain length of time, suddenly cease, and then, after a certain lapse of time, begin to flow freely again; and this alternate ebb and flow may occur with great regularity for an indefinite period. One explanation of this intermission is simply that the water collects in a siphon-shaped cavity in the rock, and when it reaches a certain height it is siphoned off. Once the water is siphoned off, no further flow can take place until the water has risen to a certain height again.

The regularity of some of these intermittent springs is very remarkable. In the Pyrenees, at Fontesorbe, a spring in summer flows for 36 minutes 35 seconds, and then intermits for 32 minutes 30 seconds. At one time there was a spring in Westphalia, known as the Bullerborn, which gushed forth every four hours with sufficient force to turn the wheels of several mills.

In some instances it is probable that the intermittent flow of springs is effected by gas-pressure. The gas accumulates in the rocky reservoir containing the water, and after a time acquires sufficient pressure to eject the water. Then there is a pause till the water and the gas accumulate again. The "English Well" in the canton of Berne, which flows a few hours every morning and again every evening, is probably regulated by gas. Other intermittent springs are due simply to intermittent supplies of water through the soil, such as is produced in certain districts by the melting of the snow by day and the freezing of it by night.

The depth water can penetrate is not known, but gravity and capillary attraction certainly carry it down for great distances, and it is probable that it percolates down until the heat of the crust converts it into steam. The distance water may travel underground before it issues as a spring may be hundreds of miles. As a rule, the deeper and further the water travels before it springs forth, the more copious will the spring be, since depth and length imply a more extensive area of supply. In many springs the amount of water poured forth is very great. In Georgia there are springs which discharge 1400 gallons per minute; in Virginia there are springs that discharge 6000 gallons per minute; while the springs of Banff, in the Canadian Rockies, discharge fully a million gallons per minute.



A diagrammatic cross section showing the different kinds of wells. An ordinary well extends for only a comparatively short distance below the water table; a deep well penetrates far below this level. An artesian well taps the water resources that are imprisoned between two impervious beds of clay.

SOME NOTABLE HOT SPRINGS

Ewing Galloway

Hot Springs, Arkansas, has long been famed for the springs that gave it its name. The Maurice Therapeutic Pool, above, is fed by these springs.

New Zealand Gov.

Maori woman cooking in a hot pool in the town of Rotorua, North Island, New Zealand. Rotorua lies in the middle of a volcanic district in which numberless hot springs are to be found. These springs are noted for their medicinal properties.

Ewing Galloway

Hot springs are utilized by this public laundry in the outskirts of Reykjavik, the capital of Iceland Other springs furnish hot water that is used to heat a number of buildings in the capital city.

If the subterranean reservoirs supplying a spring are much higher than its point of exit, the issuing water may form a natural jet. At Chatagna, in the department of the Jura, there is a natural fountain leaping to a height of 10 or 12 feet. In a grotto near Saint-Etienne there is a spring that leaps about 24 feet in height. The tendency of all these fountains is to raise a conical mound of sediment round their orifice or exit until the top of the mound is as high as their jets of water. This has happened in the case of the famous Springs of Moses, on the shore of the Red Sea, where every spring is surmounted with its own little cone.

In some cases there are springs in the sea: "Freshwater springs come up thro' bitter brine." Such springs have been known since the days of the ancient Phoenicians, famed for their knowledge of ocean lore. The water derived from these springs rises to the surface, since fresh water is lighter than sea water; in some cases there is such a rush of fresh water that a noticeable bubble is produced at the surface of the sea. Springs of this sort are found only in coastal areas; they are never found far out at sea. It is thought that these freshwater springs in the sea may be caused by underground rivers discharging their waters into the ocean far below the surface. There are such springs in the Persian Gulf, and boatmen sometimes dive into the Gulf and fill their water-skins with fresh water. These springs, which are warm, are probably supplied by the rain on the green hills of Oman, 500 miles away.

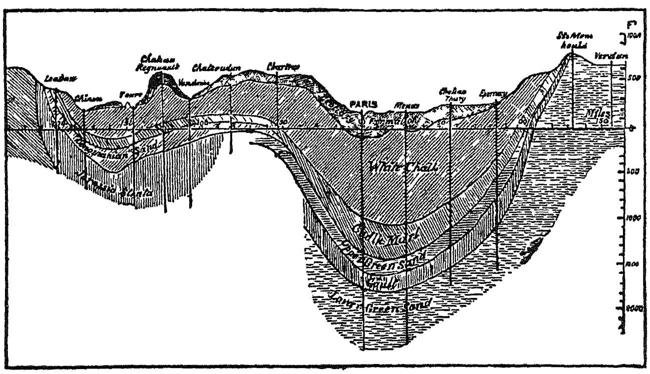
In many cases underground water does not naturally come to the surface, and can be reached only by driving wells; and in dry countries and deserts, where there are few rain-showers and no rivers, wells are essential to existence, and have been bored or dug from time immemorial. Even the primitive dweller in the desert knows how to sink a well — the indispensable means of securing the prime condition of life — and will sometimes attain a depth of about 100 feet.

The modern water-finder, with his hazel rod, seems to belong to the category of charlatans, and his success, when not the result of a shrewd guess, is probably due to the fact that there is subterranean water almost everywhere: but the modern geologist and engineer, working together, have greatly developed the science of water-finding and the art of well-sinking. The geologist can tell the course probably taken by subterranean water, and the engineer will bore through clay, sand and rock sometimes for hundreds of yards to give exit to it, until the desert blossoms like a rose.

The most important wells are known as "artesian". These wells depend upon a certain disposition of permeable and impermeable layers of the soil, as shown in the diagrammatic section on page 2848. The most efficient formation is had when a basin-shaped impermeable layer is covered by a permeable layer, and this again by a smaller, basin-shaped, impermeable layer; under these conditions it is clear that water can percolate between the two layers and accumulate there, just as water might accumulate between two saucers if a smaller saucer were placed in a larger one with a layer of earth between. It follows, too, that if a hole be made in the upper, smaller, impervious layer, the water between the two layers will rise in the hole. It follows, too, that the height to which the water will rise will depend on the curvature of the two layers, and the height to which the water rises in the permeable layer between. When the curvature is great, and walls of water rise high between the two impermeable layers, the weight and pressure at the bottom of the curve of impermeable material will be great; and if the water be given an outlet by boring through the upper impermeable layer, it will rise correspondingly high with corresponding force.

The London and Paris Basins are two typical formations of this kind. The supply of such a basin is very large, but the flow generally diminishes in force and volume when the number of wells is greatly increased; this has occurred notably in the London Basin and at Denver, Colorado. The wells first sunk have the entire accumulated supply of the basin to draw from, while later on only the rainfall which percolates into the basin is available.

In the Paris Basin the famous Grenelle well, which is about 1800 feet deep, with a bore of ten inches, discharges at the rate of 517 gallons a minute, or almost 750,000 gallons a day; while the well at Passy, also in the Paris Basin, which was sunk a little deeper and with a very much larger bore of two feet four inches, gave a discharge of about 5,600,000 gallons a day, throwing the water to a height of 54 feet above the surface of the ground. The chalk spring near Ware, England, which is the source of the New River, discharges 4,500,000 gallons a day. A number of artesian wells in the United States also give a very large supply, that at St. Augustine, Florida, for example, giving out through its twelve inch bore as much as 10,000,000 gallons per day. Initial discharges of tremendous volumes of water also occur; thus Robert Brown, in "Our Earth and its Story", gives the following remarkable instance of an artesian well flood: "During the autumn of 1886 an artesian well in Belle Plane, Iowa, by the violence and copiousness with which it spouted, threatened, for a time, to do serious damage to the town. Its diameter was four inches; and when the depth of 181 feet had been reached in boring, a volume of water rose, and rushed up with such impetus that it formed a *jet d'eau* several hundred feet high. This gradually increased in size and volume until a stream of water 16 inches in diameter was formed, and the upward force of the stream was equal to the force of gunpowder. Two 'gigantic rivers' — to quote the language of a correspondent — were accumulated by this outburst, which ran through the town at the rate of twelve miles an hour, carrying everything before them. The panic caused was naturally great. An attempt was made to insert 16-inch boiler-tubes into the well, but these were instantly blown out and forced high in the air. Fifteen cartloads of stone were then emptied into the well, but these were tossed upwards as though propelled by a charge of giant powder. For several days the flow continued unabated, and then gradually subsided to the more moderate discharge now characteristic of the well." This gives us some idea of the tremendous hydraulic pressure that can be exercised by subterranean water.



THE BASIN IN WHICH PARIS LIES — A SECTION
Horizontal scale, 125 miles to the inch. Vertical scale, 2100 feet to the inch.

The depth to which wells must be bored varies greatly, according to the varying geological formations of the region; thus along the Atlantic coastal plain, from New York down to Texas, the wells generally give a good supply when drilled a few hundred feet, generally from 100 to 300, while in the more mountainous regions the depths range from about 1000 to near 5000 feet; thus there are noteworthy wells at Edgemont, South Dakota, 2965 feet deep; one at Pittsburgh, Pennsylvania, 4625 feet deep, and one at Columbus, Ohio, 2775 feet deep. There are exceptions, however, to the rule indicated above, and the deep well at Galveston, Texas, goes down 3071 feet. In Europe there are also some very deep wells, those at Sperenberg, near Berlin, and at Schladenbach, near Leipzig, being 4194 and 5735 feet deep respectively. There are also some wells from 1000 to 2500 feet deep in Egypt and China which seem to have been drilled in very ancient times.

Since the temperature of the crust of the earth progressively increases with depth, it naturally and necessarily follows that springs whose water has traversed the depths of the crust are heated more or less. Springs which issue with a temperature higher than the temperature of the soil are known as "thermal" springs.

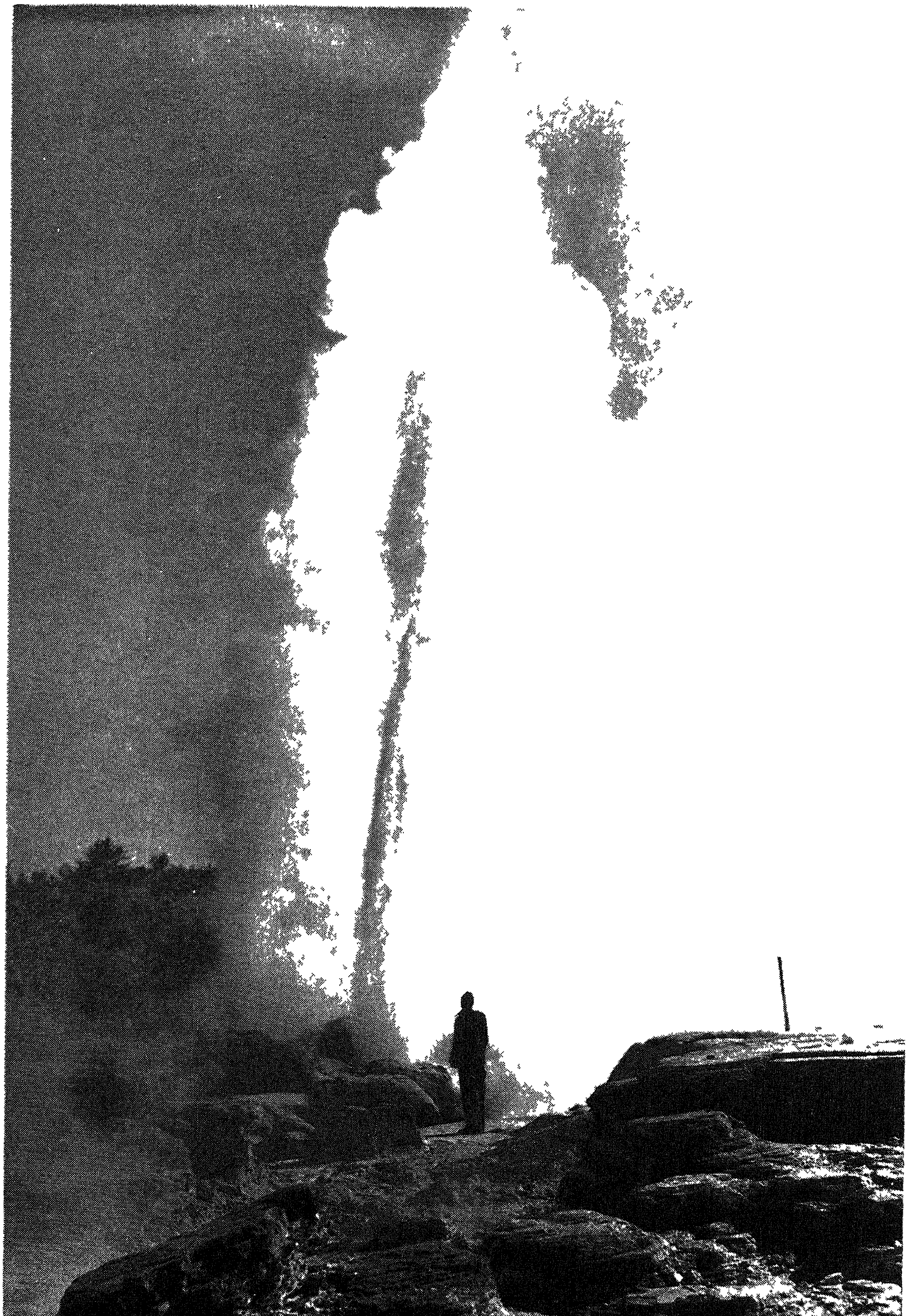
The temperature of the Grenelle well, already mentioned, which is about 1800 feet deep, is 82° F. The springs at Bath, England, issue at a temperature of 120° F. The temperature of the Las Vegas springs, New Mexico, is from 110° to 140°; of the San Bernardino Hot Springs, from 108° to 172°. The famous Carlsbad Springs in Bohemia have a temperature of 165° F., and those of Baden-Baden range from 111° to 154°. In volcanic regions there are springs which are boiling hot, and at certain localities steam is given off instead of water. The special class of hot springs known as "geysers" are treated in a later chapter.

The hottest springs in France are those of Chaudes-Aigues. The temperature of the water varies from 158° to 176° F. The hot water is utilized by the townspeople in cooking and washing. "Wooden conduits, erected in all the streets of the town, supply on the ground floor of each house a reservoir which serves to heat it during cold weather, and thus dispenses with fires and chimneys. In summer, small sluices, placed at the entrance of each conducting tube, stop the warm water, and throw it back into the rivulet which flows at the bottom of the town." At Aix-la-Chapelle the hot spring water may be drawn from spigots in the streets for domestic purposes, while at Wurtemberg the heat of a hot spring is utilized for maintaining a constant temperature in manufactories; and hospitals, conservatories and fish-ponds are sometimes heated in the same way.

In Tuscany near Volterra a means has already been found to utilize subterranean heat as a source of useful energy. Throughout the region numerous jets of very hot steam under considerable pressure issue from cracks in the ground. Pipes were laid and some of the steam collected and sent through steam engines. It was found, however, that the salts and sulphuric acid carried over by it rapidly corroded the machinery. The hot steam is now utilized to generate steam in special boilers at a pressure of two atmospheres. The latter drives turbogenerators which supply electrical power to the neighboring industries. A 3000-KW unit was placed in operation in 1916, and several others have been added since.

All springs are in some measure mineral, since rain-water as it percolates through the soil must inevitably dissolve some of the mineral matter it traverses. The minerals most commonly found in spring water are calcium and magnesium salts, especially the former. Limestone is particularly pervious to water, and most springs percolate through limestone during some part of their career. The amount of calcium salts water can gather in the course of its travels is well seen in the stalagmites and stalactites, in the incrustations that gather in boilers. Certain so-called "petrifying" springs contain so much calcium carbonate in solution that any foreign object placed in their waters becomes covered with a calcareous coating. It is true that the carbonate is almost insoluble in pure distilled water, but rain-water as it falls absorbs a certain amount of carbon dioxide from the atmosphere, and water containing carbon dioxide dissolves the limestone quite readily.

The deposition of lime around springs often takes very picturesque and beautiful forms. Reclus describes the springs of Hammam-mes-Khoutine, in Algeria: "Most of the deposits are of a dazzling white hue, striped here and there with bright colors, and are developed in mammillated strata; other concretions accumulating gradually round an orifice have taken the form of cones and are like the small craters near a volcano, some of them rising to a height of as much as 33 feet; lastly, there are masses of travertin which stretch out in a kind of wall below the flow which deposits them. One of these walls, which is interrupted at intervals by heaps of earth upon which large trees grow, is not less than 4921 feet long, 66 feet high, and on an average from 33 to 49 feet wide." More remarkable still, he says, are the springs of Hierapolis, in Ionia, which flow over a plateau and cover it with a cotton-like deposit which is 328 feet high and 2½ miles wide. Seen from afar it looks like a great cataract, but on getting nearer, one finds that it consists of white crystal banks, over which dance real cascades.


New Zealand Embassy

A geyser near Rotorua, New Zealand. Also found in this area are colored pools, falls of hot water, bubbling mud, mineral-water springs, and cliffs delicately tinted by the chemical action of steam.

"As a spectator ascends the declivities, the masses deposited and carved out by the water appear in all their strange beauty; and one might fancy that they were colonnades, groups of figures and rude bas-reliefs which the chisel had not yet perfectly set free from their rough coverings of stone. Amid all these calcareous deposits, which have been fashioned by the cascades during a succession of ages, open a multitude of cup-like hollows with fluted edges fringed with stalactites, and these graceful reservoirs, some of which are shaded with yellow, or veined with red, brown, and violet, like jasper or agate, are filled with pure water" Here and there are the dried beds of rivulets; and above one of the widest of them is the magnificent span of a natural bridge like an arch of alabaster, streaming with glittering stalactites

Very hot springs under high pressure dissolve the silicates out of granite and other rocks, and form precipitates of opaline silicate, which are sometimes singularly beautiful There are such deposits around many of the geyser springs of Yellowstone Park and Iceland.

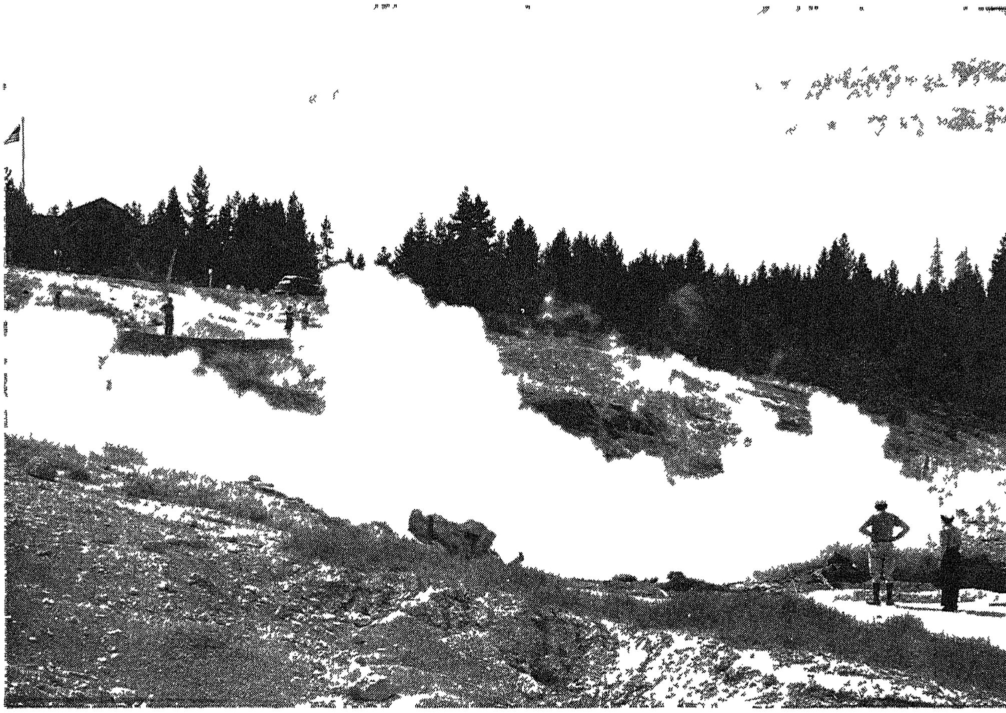
In a number of springs common salt is the predominant element. The well at Sperenberg, near Berlin, one of the deep wells of the world, is a salt spring. The brine is not derived from the sea but is formed from the beds of salt over which the water passes. Well known are the brine springs of Droitwich, Cheshire, Cheltenham and Wiesbaden. The famous fountain of Arethusa, in Sicily, was turned into a salt spring by an earthquake. In many cases the wells produce thousands of tons of salt a year In northern New York there are many salt springs and wells which were known centuries ago by the Indians and which are frequently mentioned by the early French Jesuit missionaries; those along the shores of Lake Onondaga, particularly in the vicinity of Syracuse, were described by Father Simon Le Moine in 1654; these salt lands were purchased from the Indians by the state, and from the springs and wells at Syracuse millions of bushels of salt were derived annually for a long time.

Some springs contain iron in notable quantities, so that their water has an inky taste. The water of the famous iron spring of Langenschwalbach, near Wiesbaden in Prussia, contains, when fresh, .37696 of protoxide of iron in 1000 parts. Sulphur springs are fairly common, and are usually easily recognized by their characteristic smell of rotten eggs Most mineral springs containing any considerable amount of mineral substances have medicinal properties, and all over Europe there are famous mineral springs frequented by thousands of invalids Well known are Carlsbad, Vichy, Aix-les-Bains, Aix-la-Chapelle, Harrowgate, Bath, Buxton and Strathpeffer In the United States there are also a number of famous mineral springs such as the Saratoga Springs, N Y; those at Mount Clemens, Michigan, Bath, Virginia; Hot Springs, Arkansas; Waukesha, Wisconsin; Warm Springs, French Broad River, Tennessee, and many others

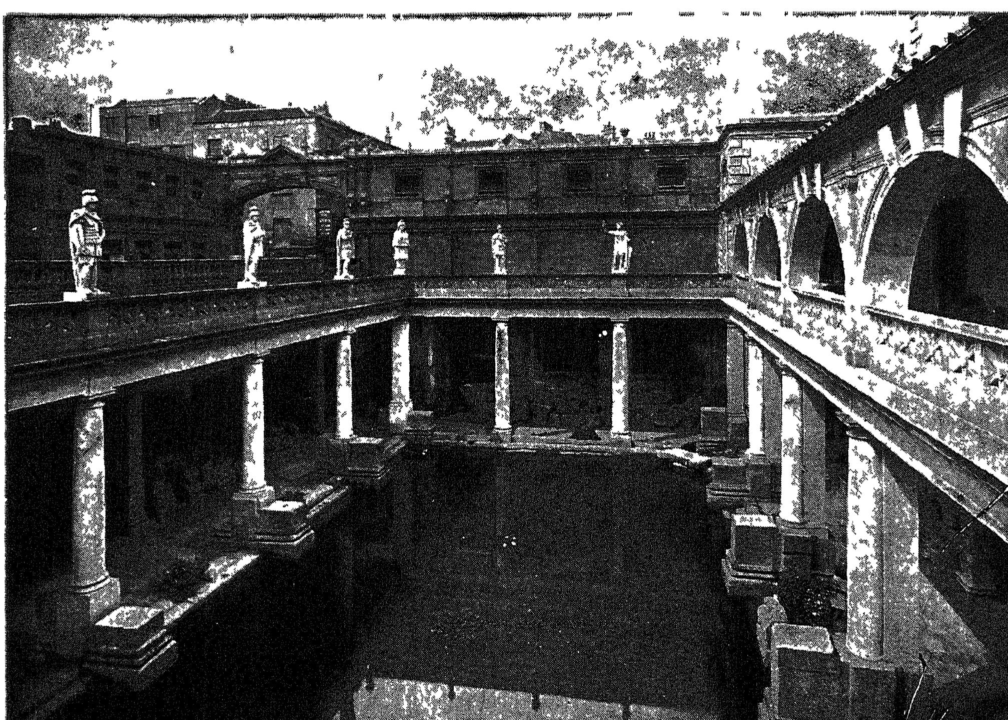
The medicinal value of the waters is undoubted, but there is a tendency to overestimate their value; and probably many cases of cure which are attributed to mineral water are really due to change of air and change of food at the watering-place. Recently it has been shown that many waters, such as those of Bath, England, contain radium; and it is possible that the healing virtues of various waters are due to radioactive substances contained in them.

Apart from their recognized healing virtues, the mineral substances contained in spring water are of physiological importance; for water absolutely pure would be dangerous, or at least deleterious, to drink. The effect of pure water is to set up an osmotic flow, so that the cells lining the stomach and intestines absorb an excessive amount of water, which causes the tissue to deteriorate.

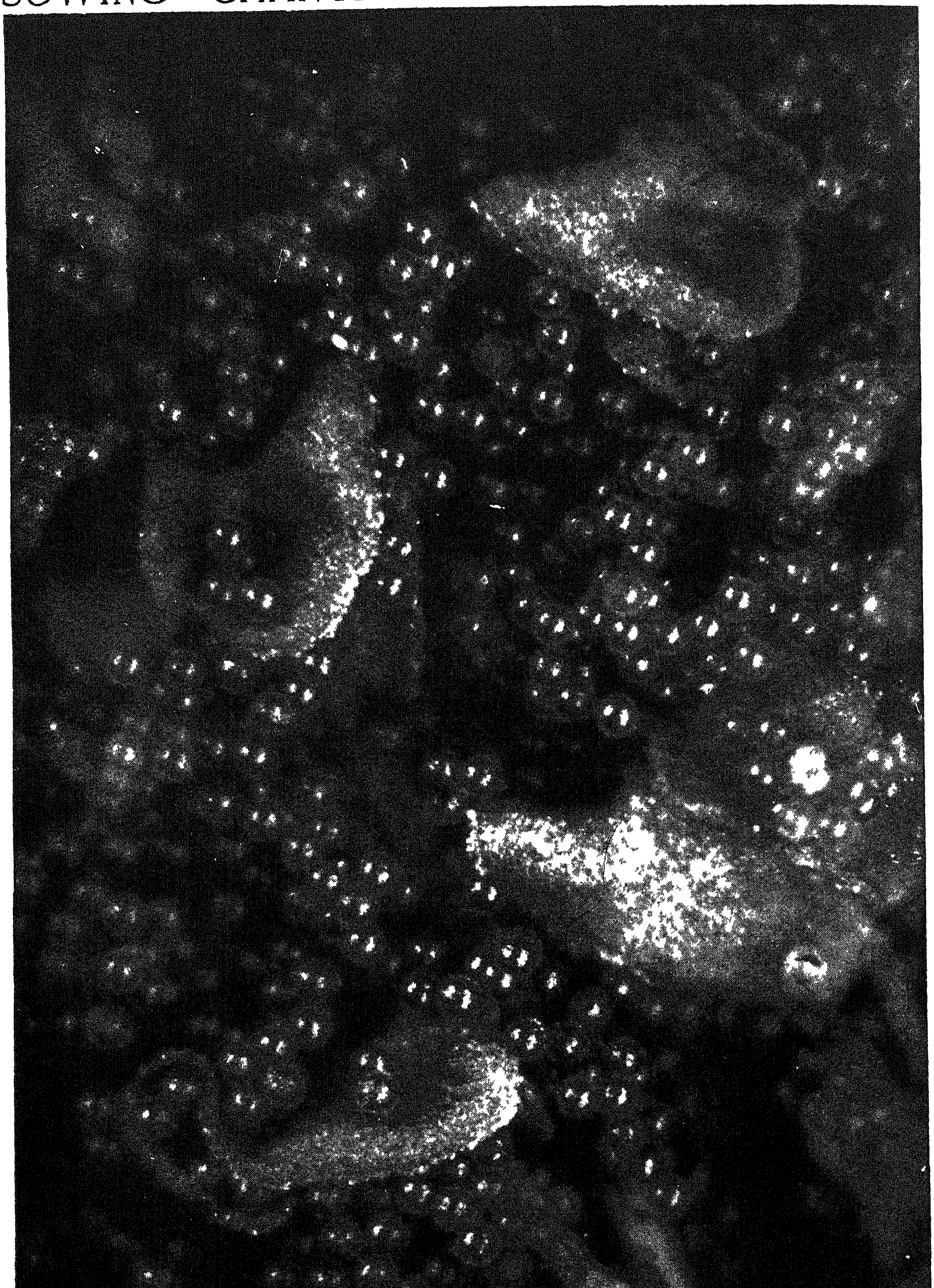
Besides mineral substances, spring water always contains a certain amount of the atmospheric gases, and in some cases the water bubbles and effervesces with carbonic acid gas. Within the last few years, too, it has been shown that the water of certain springs contains an appreciable quantity of the rare gases helium and argon.



IN THE NORRIS GEYSER BASIN, YELLOWSTONE NATIONAL PARK



THE RADIUM-TINCTURED ROMAN WELL AT BATH, ENGLAND



In this highly magnified photograph by J. J. Ward ripe pollen-grains are to be seen falling from the stamens of a mallow flower—an enormous quantity of living cells. Each grain, on germination, gives rise to a pollen-tube within which are produced the germ-cells bearing the male factors for reproduction to combine with those of the ovum-cell contained in the ovule, which is developed within the ovary.

EXPERIMENTAL BIOLOGY

The Need for a Wider Scheme of Experiment in the Region of Physiological Chemistry

PIONEER WORK OF LOEB AND MAC DOUGALL

WE have already seen the startling results which followed the return of biology to experiment. Darwin's magnificent work arrested, fascinated, irritated his contemporaries and followers, and they all set to work, hammer and tongs, attacking each other, and arguing out the meaning and consequences of the Darwinian theory, its relation to Genesis, and so forth; and the actual gathering of new knowledge under exact conditions languished for decades. At last — but it was a long time, from 1859 to 1900 — came the rediscovery of Mendelism, which started experiment again; and we have followed its results with some closeness up to the point which they have now attained.

All this experimental breeding, which yearly increases by leaps and bounds, and gains knowledge and power in all directions, is plainly entitled to the name of experimental biology. But there are other questions, open to experiment and of high importance, which are even deeper in their probing of the mystery of life and which under the name of experimental biology are now receiving attention in this country. Experimental breeding, as practised by Mendel and Bateson and their followers everywhere, has strictly confined itself to limits which are really very narrow indeed, when looked at rightly, even though they permit of such great results. These inquiries, after all, do no more than concern themselves with the passage of certain "factors" from generation to generation, their couplings and repulsions and consequences. This is no small matter, if the "factors" in question determine the characters of living individuals in general, from the lowest bisexual forms — such as, say, the parasite of malaria — up to the highest, in whose blood that parasite conducts several of its genetic stages.

But it is evident, on consideration, that two very large problems are wholly untouched by all the foregoing work, colossal and fruitful though that be. One is the problem of the effect of altered conditions upon the development of living creatures; for let us not suppose that, because we have lately learnt so much about heredity or "nature", environment or "nurture" no longer remains. The field is almost or wholly infinite, and practically untilled. That is one department of experimental biology to which we must devote some attention here — meanwhile trying to imagine how strangely our few words and meager facts will read to the historian half a century hence, when the work started by Loeb has gone as far as, say, modern electricity from the researches of Faraday.

But there is a second field for experimental biology which is no less important. Its recognition and entrance are later in time than the work of Loeb, but earlier in order of logic, and we must begin with this question accordingly. It is the experimental study of the origin of variations. We remember that, for all its performance and incalculable promise, genetics as it is at present understood deals with the passage and combination and separation and distribution of "factors" the existence of which is already assumed. Sometimes a "variation" may arise because two of these factors have come into novel association in a germ-cell or a zygote.

But that tells us nothing as to the actual origin of new factors, though only by and in such origin has organic evolution occurred. The hope arises, therefore, that we may be able to learn something as to this truly fundamental question by means of experiment, which need not be particularly difficult of accomplishment.

Thus, we have the vegetable world at our disposal, with the "germ-plasm" of most plants easily accessible, the generations succeeding one another rapidly, compared even with our own brief lives, and no practical difficulties — as, for instance, the question of cruelty to animals — in our way. Yet here, again, for some unknown reason, little or nothing was done along the necessary lines in Europe, and to the United States belongs the credit for the creation of this new development of experimental biology. What has been done, and remains to do, will be clear enough if we look afresh at the nature of the problem, and especially if we contrast the appearance it presented to Lamarck with that which it wears for us.

The superseding of the vague ideas of Lamarck and Darwin

For the great pioneer of a century ago everything was necessarily vague. He believed that, somehow, circumstances act on the body of a parent in such wise that the offspring are other than they would have been, and that their other-ness may be novel and useful and progressive. There is no confusion in science like that which commonly prevails here; and the reader must observe that we are not mentioning that subordinate part of Lamarck's theories which is usually spoken of as the whole — namely, the supposed enlargement of a future son's biceps because his father is a blacksmith and enlarges *his* biceps. We here allude to the essential part of Lamarck's theory, which was that altered circumstances alter the structure of living things in correspondence to them — as, for instance, that the occurrence of light would incite the formation of eyes — and that these changes, so produced in the individual, were somehow inherited by its offspring.

But Lamarck could not possibly know anything of the exact physical and physiological relation of parents to offspring, as we know it now. For him, as for Darwin, with his theory of "pangenesis", the new creature sprang from the *whole* of the body of its parent, every part of which was somehow represented in the living material from which the new creature developed.

Darwin, as we remember, put forth what seems to us now to be the fantastic theory that all parts of the parental body gave off "gemmules" which gathered together to form the germ-cells. Now, if we are to attack the problem of the origin of variations, the actual genesis of the "factors" whose subsequent exodus Mendelism so successfully traces, we must begin by clearly seeing what the nature of the problem really is, and how immensely different from Darwin's idea of it. Once we have gone so far, we shall be in a position to make experiments exactly designed to "touch the spot", and to profit by the results obtained by them.

The modern view that new characters come into existence in the germ-cell

Everything turns upon the making of the germ-cells. The germ-cell, or gamete, contains its endowment of factors, and is what it is, and will be what it will be. It meets another such germ-cell, from an individual of the opposite sex, and that second germ-cell also has its factors. The new individual or zygote, formed by the yoking of these two, is primarily determined by, first, the factors these two germ-cells contain, and second, the way in which the two sets of factors react upon each other. Granted so much, we see that if the individual exhibits a new character, a true original variation, not a merely novel combination or separation of "factors", but something *more* than before, like the wings of a bird compared with a wingless reptile, or the brain of man compared with the brain of the ape, this new character came into being somehow *when the germ-cells which formed the new individual were made* or, at the least, when one of them was made.

A restatement of Weismann's celebrated germ-plasm theory

The unexampled brain, the wonderful wings, or whatever the really new thing be, has its root-possibility in the germ-cells. Hence these germ-cells have the novelty in them, and *their making is actual evolution there occurring*. This has to be emphasized because all future advance of our knowledge must spring from the clear perception that original variation is something which happens when germ-cells are made.

We must remind ourselves, therefore, of the facts, so far as they have been outlined. The making of germ-cells, or genesis of gametes, is now known as gametogenesis. It occurs only in the pre-appointed tissue, to which Weismann gave the general, all but "mystical", name of the germ-plasm. It occurs alike in both sexes, any differences being relatively unimportant. Its continuance characterizes what we call the reproductive period in the life of any individual, for it alone makes reproduction possible. The length of this period varies very widely in different species. It may be only a few hours in some insects or in some plants; it may be a period of many decades in some long-lived mammals, such as the elephant or man, or in some reptiles. In many species the period may be more prolonged in one sex than in the other. In all it coincides with the occurrence of gametogenesis; it is the period during which the gametes are being formed. True, they are not being formed from the body of the individual at large, as Darwin supposed; the gametes are formed from a special, separate, predestined tissue in the parental body, but not of it.

Important limitations of the theory of Weismann

This true and valuable idea of Weismann unfortunately succeeded in misleading many of us, for many years, into the idea that the actual germ-cells already exist, preformed, in the body of a young individual, and simply leave that body at intervals during its maturity, as we see the pollen grains being shed from a flower, to choose a typical instance.

The precise character of the facts was overlooked by commentators and critics, though it need hardly be said that there is not a line in Weismann's treatise to excuse it. The facts are, first, that the young individual does bear within itself a special portion, "the germ-plasm", of which it is the host, and which has a special origin and an utterly different destiny, for it may live on in the bodies of all to come, while the individual body which carries it will soon die; and for clearly demonstrating this we shall ever be grateful to Weismann. But it is also true, has been known for decades, and can be observed under the microscope in myriads of instances at a few minutes' notice, that notwithstanding this "continuity of the germ-plasm", the actual gametes or germ-cells are formed during part (the reproductive period) of the life of the individual, from the germ-plasm, which is nevertheless itself of such vast antiquity, and which, as a whole, was not exactly made *from* the individual body.

We begin to see what must be the meaning of this fact, that though the living material which is the source of the germ-cells is not made by the individual, nor during the life of the individual, yet the actual germ-cells are so made. Consider the immense contrast between the actual case, and what is too often supposed to be the case, from the standpoint of what it makes possible.

The germ-plasm like bullion, that may be minted individually

The current misunderstanding of Weismannism is that the individual is born with, so to speak, a number of definitely minted coins in a special pocket, and that the reproductive period is that during which these coins may be spent. The fact is that the individual is endowed, even at birth, with a quantity of some material, more like bullion, of peculiar origin and destiny, meant for the construction of very definitely minted coins, each a little different from any of the others, but none of them minted as yet. These coins, the germ-cells, are minted during the reproductive period, and the process of mintage is called gametogenesis.

Now observe how extremely limited, on the view that the coins are already minted from the first, is the possibility that the life of the individual who bears them can affect them in any direction. It was thus — because this was the popular idea of Weismannism, — that arose the notion of the germ-cells as living in a world apart, where nothing that happened in *our* world could touch them.

The effects of nurture upon individual development

On this view, long declared to be the last word of wisdom on the subject of organic evolution, it was declared that the germ-cells were inviolate, utterly immune to all external influences (this being what the "non-transmission of acquired characters", like the blacksmith's biceps, was supposed to mean); and it amounted to this in the teaching of the so-called Weismannians: that evolution could never occur, variations were impossible, for no cause of variations existed. The germ-cells were shut up, like coins in a locked safe, until the time for them to be used. The logical necessity from this egregious argument was that evolution could never occur or have occurred, for all possibility of variation was excluded.

But it has been known for decades, long before Weismann wrote at all, that this picture of the germ-cells is utterly unlike the facts. What is called the "maturation of the ovum", the extraordinary series of processes at the end of which, and only at the end of which, we find what was then called a "ripe ovum", has been familiar for a long time; and here was demonstrably an active, living process, which meant and involved an exceptional supply of blood for nourishment and oxygen, which occurred during and characterized the reproductive period of the life of the individual, and without which an effective ovum, or female gamete, as we now call it, could not be found. That fact alone was sufficient to show that what happens during the life of the individual is not entirely to be ignored. And the difference between those days and these lies in the fact that the "maturation of the ovum" is now known to be a particular case of gametogenesis, and to have an exact parallel in the case of male gametes as well.

Life mintage in the germ can be modified by parental surroundings

Now for our theory of organic evolution — and for the very possibility of organic evolution, the importance of the occurrence of gametogenesis as a process dependent upon the life, the health, the blood or other nutrient fluid of the individual in whose body it occurs, cannot be overstated. As we saw when we referred to the suggestions made by Professor J. T Cunningham, our recognition of gametogenesis as a vital process dependent upon the vital activities of the individual in whom it occurs clearly opens up the possibility that those vital activities may affect gametogenesis, and therefore the characteristics of the gametes in which that process results. In other words, we find ourselves compelled to make a fresh start, and study from the beginning the influence of the parental body upon the details of gametogenesis. This may mean the discovery of the cause of variations, and therefore of organic evolution; it directs us to the real "origin of species", which Darwin did not discuss. Everything, in short, which Weismann's influence led most of us to regard as a matter which had been disposed of, on the ground that the germ-cells were minted coins from the first, must now be studied anew. The mintage, we see, occurs during the reproductive life of the future parent, and may be modifiable thereby to an extent of which at present we know substantially nothing.

The need for a study of the effects of external conditions

Here, most evidently, is an infinite field for experimental biology. In a word, we must take individuals, as, for instance, plants, the character of whose offspring we can certainly predict (if we take several individuals and repeat our experiments); and then we must modify those individuals in ways which, we are sure, must touch the "germ-plasm", and must see whether they now bear offspring of another kind.

If the offspring are different, we can be sure that we have somehow modified the process of gametogenesis in the parent individuals, so that it results in gametes which are not what they would have been without our interference. This is a department of the study of life which, we now begin to see, transcends in importance anything that even the Mendelians have demonstrated hitherto. Not that they are to be blamed — except in so far as they have their share of responsibility for the general neglect in other countries of the work done by the American botanists. The Mendelians have their own initial task before them; and it is clear that, until they have found out what normally occurs in heredity, we cannot usefully make any experiments as to the effects of altered conditions of parental nurture.

The problem of external influence one of physiological chemistry

It has been made evident by the Mendelian work that to ascertain the normal facts under constant external conditions is the first necessity. And as for a certain amount of experimental work upon the influence of varied parental nurture, done in the nineteenth century, before Mendel's work was known, all that must now be repeated, simply because it is only now that we begin to know what to expect *before* we vary the conditions.

The problem is essentially one in what is called physiological chemistry. We think of it no longer as either Lamarck or Darwin did; we think of it not in terms of the action of external conditions upon the parental body as a whole, but in terms of the action upon the "germ-plasm" of *its* environment. Now, the environment of the germ-plasm is the body which bears it, and the details of this environment vary widely in different cases. If, for instance, we consider the germ-plasm of a flowering plant, and that of any of the higher animals which correspond in the animal world to the flowering plants in the vegetable world, we see notable resemblances and also notable differences. The germ-plasm of the plant, as we see it, or imagine it, giving rise to the male and female gametes, is by no means free from something very like the *immediate* action of the environment. We are now acquainted with many of the properties of light and ethereal radiations, and we have been taught how potently the electrical state of the atmosphere may affect the growth of plants. Knowing as we do how many of these rays can penetrate matter to a considerable degree, we see that the germ-plasm of a flower, in which the process of gametogenesis is occurring, can no longer be regarded as something utterly withdrawn, free from any possibility of modification by the direct action of the external world.

The study of radioactivity on germ-plasm in plant life

The effect of physical and chemical stimuli on cells is being closely studied here and abroad. The action of radioactivity and of the Rontgen rays upon dividing cells is known to be immense, as the medical observation of their action upon cancer and normal cells has proved; and in many instances the whole type of the cells under their influence can be altered, as when prolonged exposure to the Rontgen rays produces a terrible change in the nuclear division of normal skin-cells, and so forms malignant growth, which is, in a very true sense, a *variation* in the cell-type of the part affected.

It is known that in certain types of rabbits low temperatures cause newly-formed hair to come in black, whereas at higher temperatures hair on the same parts of the body will grow in white. The discovery of the abundant gene mutations produced by X-rays was made almost simultaneously by Muller, Stadler and Goodspeed in 1927. This was an epoch-making discovery, and it has since been shown that these X-rays produce profound effects ranging from mutations in a single gene to rearrangements and reassortments of entire chromosomes. When these facts are remembered, we see that the study of the action of radiation upon the germ-plasm of those forms of life in which, as in most plants, the germ-plasm is almost freely exposed may yield results of unlimited importance. New frontiers have been opened for investigation.

The ovary within the animal body is not usually as prone to influence by external radiation. This withdrawal of the germ-plasm, in so many animals, as if no outside fact could affect it, has misled many writers into the supposition that the animal germ-plasm, at any rate, is usually to be reckoned as proceeding on its appointed vital course without any relation to the rest of the Universe at all.

Other life equally responsive to influences of environment

How absurd that assumption was we see when we observe the respect in which the germ-plasm of a rose and of a rabbit, so differently placed in relation to the direct action of the environment, are similarly placed in relation to the body in which the germ-plasm is housed. In both cases it is clear that the life of the germ-plasm depends upon the life of the individual to whom it belongs, or who belongs to it, as Weismann would prefer us to say. Gametogenesis is the essential expression of the life of the germ-plasm. It consists of cell-formation, the cells formed being discharged in various ways when the proper time comes. If we weigh the pollen-cells that leave, for instance, the head of a dandelion, or estimate the weight of the germ-cells produced during the reproductive period of any of the higher animals, we see at once that a relatively enormous quantity of living matter is produced in and by the cells of the reproductive tissues — in and by the germ-plasm.

The effect of gametogenesis of the nutritive state of the individual

This means necessarily that material of various kinds, albumins and salts and water and sugar and fat, have been supplied to the germ-plasm by the blood and lymph, in the case of an animal, and corresponding substances in the nutritive fluids of a plant; and in each case the vital activity of the germ-plasm has formed, by the process called gametogenesis, the "ripe", mature or final gametes which primarily determine the characteristics of the next generation. There can be no criticism of the assertion that the process of gametogenesis must therefore in part depend upon the nutritive material which is supplied to the germ-plasm during its occurrence.

This has been clear enough in a limited range of instances, wholly morbid and exceptional — namely, the action of such substances as alcohol, to which the name of racial poisons has been given. All that question has its own importance, from some practical points of view, and it is further important as leading to the demonstration that the nutritive state of the individual may affect the gametogenesis occurring in that individual. But the effects here are for the worse; they are degenerative, and, if long continued, lead to the extinction of the species. Nothing of that is of any service to our problem, which is to explain not the destruction or degradation of high forms of life already evolved, but the upward process by which their evolution occurred. We want to know whether the modification of the nutritive fluids of the parent may ever cause true, healthy, original variations in the offspring. After many decades of argument, the business of putting this fundamental question to the test of experiment has been begun in America.

The development in America of new forms of offspring by chemical experiments

Professor Robert Mac Dougall, of New York, has succeeded in modifying gametogenesis in plants, so that the gametes were other than they would have been, and thus the offspring developed from those gametes exhibited true, original variation. An essential distinction between this demonstration of Mac Dougall's, and the work done in Europe upon the action of alcohol upon gametogenesis, is that the new forms of plants produced by Mac Dougall were not morbid, not simply vitiated versions of their parents, but were types really new in certain details of their structure. They were demonstrably produced as a direct result of the introduction, by injection or otherwise, of certain unusual salts into the parent plants — the novel agent being, in some instances, introduced directly into

the ovaries of the plants, so that the chemical environment in which gametogenesis was there occurring was modified. Needless to say, many substances might be thus introduced which would kill the plant altogether, and many others which would result in the production of feeble, deformed or defective offspring. That is only too easy, and it has a bearing upon a department of eugenics. But destruction is always an easier feat than creation — any housemaid could light the fire with the manuscript of "The French Revolution", but only Carlyle could write it. Similarly, anyone can alter the life of a living thing, or of its offspring, in the direction of death and destruction. But Mac Dougall introduced salts which were not very different from those normal to the plant — at least in some instances — and he obtained forms of offspring which were genuinely new.

New forms of cultivated life that breed true and are inherited

An evident test is required before we could say that the new forms, shown in the offspring, were of the character of genuine variations, due to the formation of a new type of germ-plasm and gametes. That is the test of breeding, in their turn, from the new forms thus produced. In several experiments Mac Dougall was able to show that the new forms bred true, so that new species had definitely been formed by the action of altered chemical conditions upon gametogenesis. More remarkable still, in some instances Mac Dougall found that the new forms were inherited by successive generations according to Mendel's law, showing beyond a doubt that his alteration of the nutritive state of the original plants had really effected a change in the "factors" of the gametes produced in them. Certainly the time has come when this work must be repeated and extended by workers in other countries. Too much must not, however, be asserted for what has already been done. The new forms made by Mac Dougall could in no instance be called progressive or constructive, in the sense in which the evolution of higher from lower forms of life is progressive.

The need for study whether life is formed wholly from within

It may well be that nothing other than a Bergsonian or vitalistic conception of life will ever give us the key to its sheerly creative deeds. But no acceptance of that view of creative evolution as proceeding from within Life, and not stamped upon it from without, will excuse us for neglecting to study, as far as possible, all the ways in which alteration of circumstances, environment or nurture, alters the forms assumed by living things.

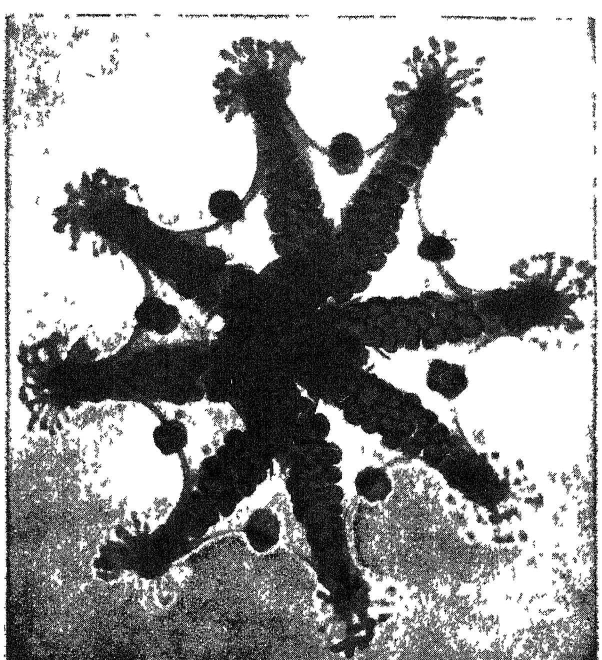
It may be that our statement of the facts should be in other terms. Perhaps we should regard the new types as adaptations to new conditions of environment, rather than as mechanical results of the new conditions. But in any case we must extend these experiments without limit, for no man can say to what they may not lead. Here we leave them, but not without once more reminding the reader that this origin of new forms by alteration of parental nurture is wholly distinct from any of the feats of Luther Burbank in this country, or of Professor Biffen in England. These workers have done amazing things by experimental breeding, and have made new living forms of great value and unquestioned novelty, but there the secret has lain in the novel combination of elements or factors or characters already existing. Genetics teaches us that the individual is a living mosaic, and has now begun to make new designs by new combinations of the pieces of mosaic. But the deeper question and problem, which genetics does not touch, is as to where those pieces of mosaic, which it juggles with, came from, and how. From this point of view, the experimental production of a comparatively trifling variation that is really original is of more importance than Professor Biffen's creation of a valuable and novel wheat by the combination of factors which already existed, but were never in combination before.

Lastly, we note that experimental biology must study the effect of varied conditions upon the development of the individual or zygote, from its first formation

onwards. It is a hard enough task to ascertain the facts of normal development — by which, after all, we only mean development under certain conditions which we regard as usual. But we must also study the facts of abnormal development — by which we may perhaps only mean development under conditions which we do not regard as usual. Here the field for study is infinite. Professor Jacques Loeb has made a beginning, and many other workers, notably in France, such as Délage, and in Germany, are at work here also. Already the evidence is conclusive that enormous effects, of the most unforeseeable and often bizarre kinds, may and do result from varied conditions of nurture which may appear to be of the slightest and most unimportant kind. Here also, as in the case which we have just been studying, destruction, deformation, vitiation, are easy to produce, and their degree is limited only by death, but it is a very different matter to produce changes of a positive or creative kind by means of any modification of the conditions of nurture during development. Destruction is easy, but construction seems nigh impossible.

On all this, where we are mere beginners, the future will pronounce. In the foregoing we have gone as far as our knowledge will at present permit towards elucidating the causes and conditions which determine the characteristics of individual organisms. Now we must pass on to study the great problems which depend on the fact that living individuals, however they come to be what they are, exist in vast numbers and in many different forms, and enter into many relations to one another, of mutual aid, hostility, parasitism, competition and so forth.

All these relations have doubtless been much overestimated, so far as their importance for the problem of organic evolution is concerned. For instance, we no longer entertain the strange delusion that the competitive and mutual destruction of species effects the "origin of species"; but these many and contrasted relations between living creatures, animal and vegetable, high and low, visible and invisible, are evidently responsible for many of the facts of the living world at any given time, and are therefore worthy of the closest study at all times.



A JELLY-FISH BEARING RIPE OVA WITHIN ITS BODY

FRUIT AND SEED DISPERSAL

The Scattering of Seeds and Fruits by
Various Ingenious Devices and Activities

TRAVELS OF A SEED BY LAND AND SEA

IN our last chapter we considered the general principles upon which the dispersal of plants over the surface of the globe was based, and outlined some of the principal methods which plants adopt in order to secure their own distribution. The subject is such an interesting one, from the point of view particularly of the special mechanisms evolved by plants in order to assist themselves in this direction, that we propose to study in a little more detail some of the most striking examples of adaptation. We have seen how plant distribution is attained sometimes by means of offshoots, runners and long underground roots, but here we wish to note more especially adaptations for the dispersal of fruits and seeds, for in these some most beautifully impressive arrangements are to be found.

Goethe, in his "Travels in Italy", describes the surprise he experienced in connection with some capsules of a plant (*Acanthus mollis*) he had brought home, placed in a box, and taken no more notice of for some time. He relates how one night he was aroused by a crackling noise, followed by a sound suggesting a number of small bodies being thrown against the walls and ceiling. On searching for a cause to explain the phenomenon, he found that the capsules had ruptured, and, in doing so, had scattered their seeds with considerable violence all over the room.

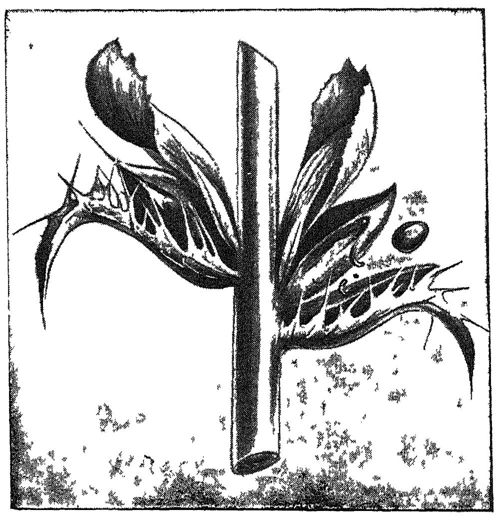
What had happened was that during the time the seed capsules had been lying in the box the dryness of the room had brought the ripeness of the fruit up to the required degree of elasticity for the capsule to burst.

A similar incident is quoted by Kerner. "On the heights of the Kahlenberg, at Vienna, at the edge of the wood, grows an under-shrub which bears the name of *Dorycnium herbaceum*. It is one of the *Papilionaceæ*, and develops spherical one-seeded fruits, which ripen in October. I once collected from this plant several twigs laden with fruit, for the purpose of a comparative investigation on which I was engaged, and brought them home and laid them on my writing-table. Next day as I sat reading near the table, one of the seeds of the *Dorycnium* was suddenly jerked with great violence into my face. Shortly afterwards I saw a second, third, fourth and ultimately about fifty seeds let fly from the small clusters of fruit, and each time I heard a peculiar sound which accompanied the bursting open of the fruits and ejection of the seeds. The rays of sunshine from the window had evidently heated and dried the fruits, and occasioned this surprising phenomenon."

These examples may serve as an introduction to the idea of the dispersal of seeds and fruits by means of special mechanisms evolved for that purpose. First of all we may note some examples of what are known as the explosion or expulsive fruits, of which the one referred to by Goethe in the above is a large group. When the fruits of these plants are perfectly ripe, the covering immediately around the seeds becomes extremely tense and stretched: indeed, to so great an extent is this the case that the tissue is actually forced to open or burst at certain parts, and the result of this is that the segments which are left contract suddenly.

In so doing they roll themselves up, and the seeds, which adhere up to this point to the segments, are expelled with the violence of the contractile movement. As a rule, it is not the whole fruit that is thrown off by this, but merely the seeds, although considerable difference obtains in different species in this particular In spite of the many variations in the contrivances in plants evolved for this object, the result is always the same — namely, that the ripe seeds are hurled to a given distance — which, of course, varies — and larger numbers are enabled to survive.

A very striking plant in the explosion-fruit group is that known as the squirting



SEED CAPSULES OF ACANTHUS, SHOWING THE EJECTION OF THE SEED

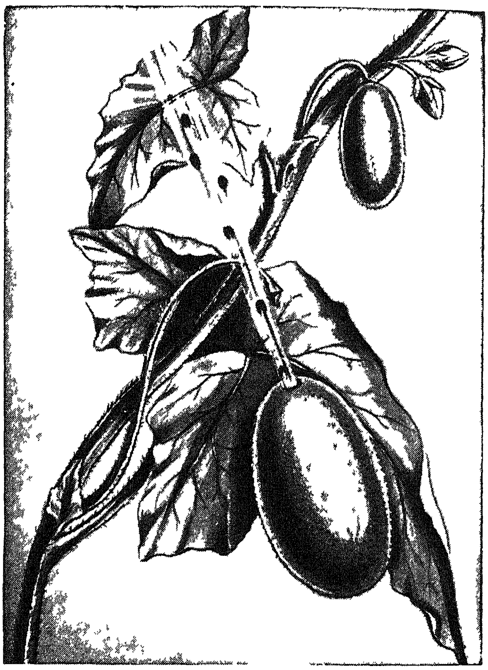
cucumber (*Ecballium elaterium*). The fruit of this plant looks rather like a small cucumber covered over with bristles and carried by a bent stem. This latter is prolonged into the inside of the fruit in such a way as to act almost like a cork to a bottle. When the seeds within are ripe, the part of the plant substance immediately around them becomes softened and gelatinous, and this has the effect of loosening the connection of the stem, or cork, with the interior. At the same time, the cells composing the wall of the fruit swell up, become turgid, and are at high tension from the endeavor to expand. Indeed, their expansion is only hindered by the firmness of the tissue immediately round the stem, or cork. When this becomes sufficiently softened, so as to loosen the latter, the connection between it and the fruit is broken, and at that time the layer of cells, which is extremely tense, becomes expanded. The total result of these changes is that the interior of the fruit is subject to great pressure, and to such an extent is this the case that the seeds within are squirted out through the aperture, which was formerly corked up by the stem referred to.

The common wood-sorrel is another of the explosion-fruits that expels its seeds in a somewhat similar manner. In this case, too, the bursting of the portion of the plant which causes the expulsion is caused by the high tension produced by the swelling of certain cells covering the seeds. In the case under notice, it is the seed-coat that becomes thus tense. The external layer of the pericarp is at the last stage unable to resist the pressure within, and ruptures in such a way as to sling out the seed through the aperture made by the rupture itself. In all these cases "the cause of the expulsion is the turgidity of cells, or the swelling up of cell-membranes with a concomitant maintenance of a state of extreme tension in a particular layer of tissue situated in the wall of the fruit"

There are, however, quite other arrangements that bring about a similar result In some cases there is a special layer of the wall of the fruit which, when it ruptures, curls itself up so quickly that the seed, or seeds, attached to it are thrown to some distance, the mechanism being something like that of a spring suddenly released. If the fruit of the wild Crane's-bill (*Geranium maculatum*) be examined, it will be noticed that the carpels, which are five in number, are swollen in the shape of a hemisphere at their base, tapering at their free ends in the form of a long beak. When the seed is ripe, the tissue composing this long structure dries up, and the beak separates itself into the five component parts, curling up as it does so like a watch-spring. This separation of the parts has the effect of exposing the cavity in which the seed lies, and the further effect of the watch-spring movement throws the seed to a considerable distance.

A somewhat similar performance is that carried out by certain violets, which possess fruits within a capsule that separates into three distinct valves These valves somewhat resemble the shape of a boat, the seeds within being arranged in two rows, like the rowers Again we have the rupture of a special layer of the fruit-wall, which is exerting pressure on the seeds within. The rupture of the capsule ejects the seeds to quite an extraordinary distance, the seeds following each other in regular succession from one end to the other, and the carpels, or boats, emptying themselves and their seeds, or crew, one after the other.

In quite a large number of other plants the fruit is provided with a number of valves, which twist themselves into a spiral at the moment when the capsule opens, the number of coils in this spiral depending upon the length of the tissue concerned. Other contrivances of a somewhat similar nature are to be seen in the Eschscholtzia, where the entire fruit is slung away; in the stork's-bill, another geranium, witch hazel, jewel-weed, castor bean and other common plants to be found in America.



SEED DISPERSAL OF SQUIRTING CUCUMBER

In each of these cases, and in others similar, the arrangements of the growth of the plant are such that, when the time comes for slinging out the fruit, no other structures are in any position to interfere with its success. For example, if the fruit in its early stage is concealed under leaves, or carried on stalks with a downward curve, as is the case in the wood-sorrel and the violet respectively, these stalks assume such an attitude as provides for the greatest range of dispersal at the moment of ejection. Moreover, the seeds themselves are of such a shape that they offer as little resistance as possible to the air, and this is attained by their being round, oval or bean-shaped.

THE EJECTION OF WOOD-SORREL SEED

It might be thought, at first sight, that the smaller and lighter the seed, the farther would it be projected, but, as a matter of fact, the case is precisely the opposite. The large and heavy seeds are thrown much farther than the small and light ones. Of course, the distance to which seeds are slung or hurled by these special contrivances is quite infinitesimal when compared with such agencies of dispersal as wind, water and animals. Probably this is why these arrangements are somewhat exceptional.

No plant, as far as we are aware, is able to project its seeds to a distance of more than 45 or 50 feet, and it is an interesting fact, illustrating how nature produces structures adapted to special environments, that the few plants, comparatively speaking, known as the explosion-fruits are chiefly found in localities sheltered from wind.

An interesting refinement of this process of dispersal, and one which renders it even more certain and effective, is found in explosion-fruits whose capsules are developed in such a way that when they are at the proper stage of ripeness they burst open upon the slightest provocation. A very slight touch from the outside is sufficient to relax the tension of the capsule, and cause the seeds to be thrown out *in the precise direction of the object which came in contact with the capsule*. This object is usually a passing animal, and the result is that the seeds are slung at the animal itself, and, surrounded as they are by a soft and sticky substance, some of them, at least, adhere to the skin of the creature. The seeds thus adhering to the animal's coat may, or may not, be irritating to its skin. If they are, they will be carried by the animals to some distance, and endeavors will be made to rid themselves of the irritating particles by rolling on the earth, rubbing against trees, or some other mechanical means of removal. If they are not irritating, they will be carried about by the animal until ordinary causes of friction determine their escape. But in either case the contrivance on the part of the plant to secure the dispersal of its seeds is obviously an eminently successful one.

THREE SEED-PODS OF THE SWEET VIOLET BURSTING OPEN

So much for the consideration of the mechanical means adopted to scatter seeds in what we have termed the explosion-fruits. Be it noted in leaving this group that in all these cases the forcible expulsion of the fruit is made possible either on account of the loss of water in certain layers of cells, or by other cells becoming more turgid.

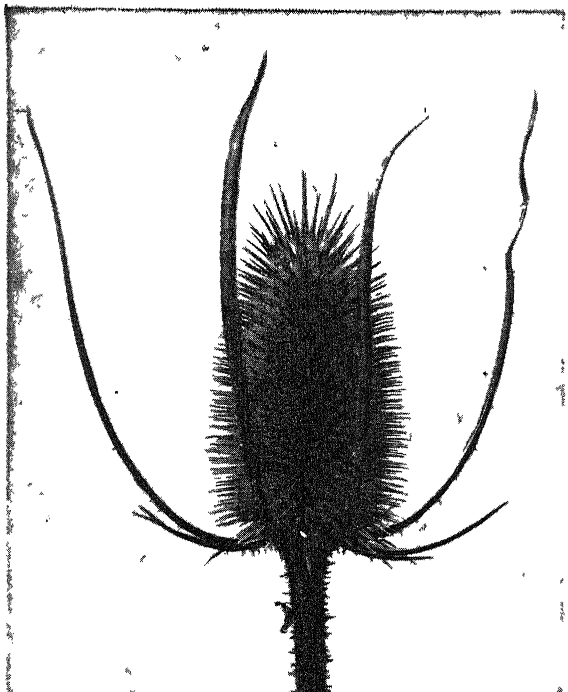
Next we may turn our attention to an entirely different method of seed-scattering — namely, the elasticity of the stalks or stems on which certain fruits are carried. These stalks and stems are kept in an enforced attitude by external agencies, and, being extremely resilient, should the compelling influence cease to operate they spring back from their elasticity into a different position, and this rapid change of attitude throws the seeds they carry to a considerable distance. The whole mechanical arrangement suggests the action of the ordinary catapult, and hence the name "catapult fruits" has been given to plants that disseminate their seeds in this manner.

Some of the simplest examples of this kind of mechanism are to be found in the common family, the *Compositæ*, where the fruits are carried upon somewhat long stems held upright, and distinctly elastic. The fruits in these flowers are small, and when they are ripe they are to be found in the middle of a disc, which has a number of scales round it. In some other cases they are deposited in a kind of basket-shaped receptacle, but in either case the fruits are unable to escape from the position in which they ripen unless some outside force is applied. This force is commonly found in the wind, or the result may be well attained by an animal rubbing against it. In either case the stem, which bears the receptacle on which the fruits lie, only requires to be bent down by the force of the wind, or by the contact of a passing animal, in order to bring about the scattering of the seed by

means of its own power of elastic recoil in its effort once more to assume the erect attitude. As this recoil takes place, the ripe fruits are scattered from the central disc on which they lie.

In some other members of the same family there is a curious arrangement of scales, which are also elastic, and in some the fruits are so arranged in compartments, as it were, that any disturbance of the whole structure moves the seeds higher and higher up these scales until they reach the summit, where they are naturally discharged, and the movements of the stem in the wind cause them to describe a curve in the air.

In still other *Compositæ* the seeds are carried in a kind of basket, which is closed as long as the weather is moist, but opens widely in hot, dry weather. Out of these baskets the seeds are thrown by means of the swinging stem, and in all these cases it is to be observed that the aperture from the fruit capsule is directed upwards, and is only open in dry weather. It follows that the seeds lying at the bottom cannot escape except when the elastic stem which carries the receptacle is disturbed by the force of the wind, or when some other external influence sets it in motion. A very large number of *Compositæ* have, in addition to this catapult arrangement for freeing their fruits from the parent plant, parachutes, wings and other devices on the fruits to assist in carrying them for long distances.



THE HEAD OF TEASEL AT THE FRUITING STAGE
The vibration of the stem causes the seeds to jerk out of the scales which act like spring-boards

Some of the fruits in the family of the *Labiatæ*, which includes many of our common plants known as mints, have a particularly interesting mode of dispersal, especially in cases where the fruit is deep down in the calyx. This latter structure is somewhat tube-shaped, and is supported by an elastic stem. If pressure be applied to the points of the calyx, the elastic stem, of course, bends in response to the force applied. On account of its elasticity, however, it immediately flies back to its original attitude when the pressure is removed, and in doing so the fruits, which are like small nuts and rounded in shape, are fired out of the catapult, as it were, with astonishing force. Not only so, but they are fired out in a definite fixed direction by means of a groove, acting in a very similar way, and with a similar result, to that in the barrel of a rifle which determines the flight of the bullet. The force of the wind, or the contact of an animal, or the weight of the water from rain may bring about the desired result.

Even with all these marvelously perfect arrangements for the securing of seed dispersal, nature is by no means at the end of her resources. Certain fruits and seeds are so constructed that they are able to travel over the surface of the ground, when once they reach it, almost as well as if they had organs of voluntary locomotion. We refer to those fruits which are described as *creeping* and *hopping* fruits, terms which express the idea, or at least suggest, that the fruits themselves can creep or hop about on the ground as if they were animals.

These creeping and hopping fruits are furnished with a number of bristles, which absorb moisture from the surrounding atmosphere According to the amount of moisture present in the air, and so varying

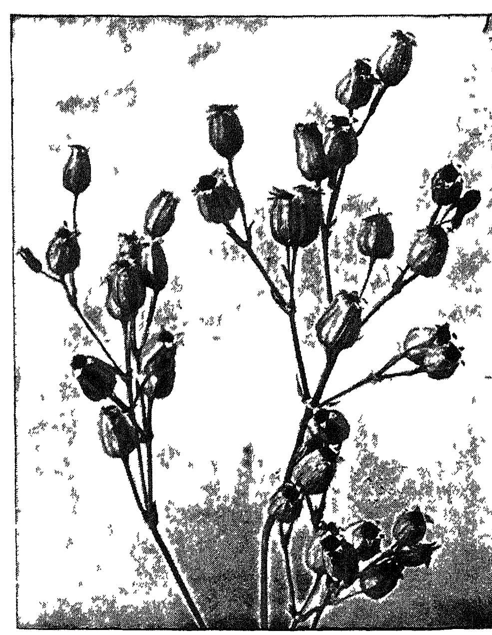

THE FRUITS OF THE CRANE'S-BILL

in its amount of absorption, these bristles change their shape and arrangement, and in so doing they actually cause the fruit to move along the ground just as definitely as if they were the limbs of a spider.

The principle simply is, therefore, that different parts of the structure alter their relative positions one to another, and so produce the creeping movement. There is one further necessity, however, before such a mechanism could be perfectly successful, and that is that the bristles, by means of which it is carried out, must have some means of getting a grip upon the surface over which they are moving. This means actually exists in the shape of a number of small teeth like the edge of a saw, all pointing in the same direction, and having the effect of absolutely preventing movement in a backward direction.

It must not be supposed, however, that the distance of dissemination attained by means of these creeping or hopping arrangements is to be at all compared with the means of dispersal afforded by wind and water and animal carriers. As a matter of fact, the result of these movements is generally to cause the fruit to be held captive in some corner from which it cannot escape, and it is possible that part of the function of these bristles is to afford a means of attachment to the earth until the seed takes root.

In the case of porcupine grass, *Stipa spartea Trin.*, this creeping device occasion-



SEED CAPSULES OF *LYCHNIS FLOSCUCULI* CLOSED AND OPEN

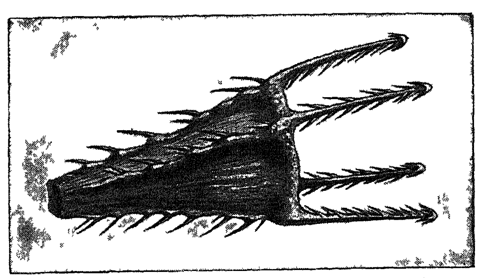
THE CREEPING SEED OF AVENA

A SEED WITH SAW-LIKE RIDGES

ally becomes vicious, when, for example, the structures get into the fleece of sheep. It has been reported that the structures are able to work their way to and through the skins of the animals, of course causing great discomfort to them.

We have seen that certain fruit capsules only open and allow their fruits to escape under the action of dryness and sunshine. On the other hand, there are some that open only upon becoming wet, as, for instance, by means of rain. In these cases it is doubtless an effort on the part of the plant to prevent the seeds being utterly dried up and lost, because plants exhibiting this phenomenon are chiefly those of dry, arid districts. In such cases, if the wind itself were able to disperse the seeds, they would probably never give rise to new plants; but, having an arrangement requiring the presence of water, as in rain, to set them free, they are also assured of finding sufficient moisture to start their growth at the time they are set free.

In a former paragraph we noticed the action of water in the shape of the ocean currents and rivers in dispersing plants, or parts of plants, and the same thing appears, perhaps with even greater force, in connection with fruits and seeds. It is perfectly obvious that a large number of air-borne seeds and fruits will be blown, sooner or later, into streams and rivers and the sea, and will be carried by these agencies to far-distant parts, where they may start new growth. Doubtless many of these perish on their enforced journey, and others will find themselves in an unfavorable environment when they are once more deposited. We are here speaking of the dispersal of the seeds of land plants, not water plants. Others, however, may be carried immense distances in this way, and be months upon the journey, and botanists have made some experiments with a view



THE BARBED FRUIT OF THE BUR-REED

to ascertaining how long certain seeds could be thus immersed in the water of the sea without losing their germinating capacity. These experiments have shown that for the plants tested the seeds are perfectly sound and able to grow after being no less than a whole year in the sea.

Needless to say this means that such seeds might be transferred from one end of the world to the other by means of some of the great ocean currents, provided they have the capacity of floating in the salt water.

This is an extremely important point, and restricts the operation of this method of seed dispersal to a much greater extent than would otherwise occur. As a simple matter of fact, there are quite a number of fruits and seeds which, when placed in water, will float on the surface, but the number that will continue to do so for anything like a protracted period of time is comparatively much smaller than might be expected.

Some of the fruits, of course, have external coverings of such a dense nature as to render them impermeable to the action of water, and to cause the fruit to float for an indefinite period. Frequently, also, in this outer coat is a certain amount of air, such as is intermixed with the fibers of the cocoanut; and this, too, helps the fruit to float buoyantly.

A word must be said here about the curious manner in which water disperses the seeds in lakes and ponds where currents are absent. There is, nevertheless, a quite definite movement in such waters, even if it cannot be described as a current, and this movement is established in relation to a different temperature at different depths This, of course, produces a vertical movement, and would not aid very much in the transmission of seeds from one shore to another. This last is brought about by the action of wind upon the surface. It will be found, if a careful examination be made, that a large number of plants dwelling in the neighborhood of marshes and lakes develop fruits contained within a capsule which floats by means of the air within it Among these may be mentioned the sedges, the water-plantains, the flowering rushes and some of the water-lilies. In all of these it is a combination of wind and water which enables the dispersal of the fruit to be brought about, the fruit being so constructed as to float upon the water, which, in the absence of currents, requires the agency of the wind to move it along its surface.

Space forbids our entering into further detail of seed dispersal, and we must content ourselves with simply stating that, besides those described, there are innumerable other special contrivances of great ingenuity planned for a similar purpose.

THE FRUITS OF ESCHSCHOLTZIA

FRUITS OF WILD CRANE'S-BILL

OUR COMMON BIRDS I

Robins, Thrushes, Chickadees, Nuthatches, Kinglets, Creepers, Wrens, Nightingales and Mockingbirds

MELODIOUS THRUSHES AND MODEST JENNY WRENS

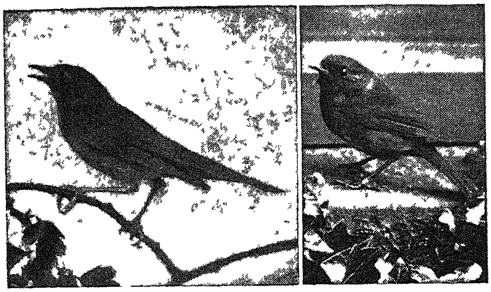
IN the noisy parks of the large cities, in the silent forests of the mountains, from the steaming lowlands of the equator to the rocky coasts of the Arctic, there is always a bird of the thrush family (*Turdidæ*) to welcome the traveler. In the cities it is the robin, the bluebird and the woodthrush; in the woodlands it is the veery, the hermit and the olive-backed species; in the tropics it is the solitaire and the "thrush-robin"; and in the Far North it is the wheatear. When we make the term "thrush" broad enough to include the ground thrushes, the accentors, the redstarts, the nightingales and the chats of the Old World, the family includes between five and six hundred species, but of these only about two hundred and forty are true thrushes. These are widely distributed throughout the world, but eighty of them are confined to the New World, of which only a dozen species are found north of Mexico.

As a family, the thrushes are medium-sized birds, usually under twelve inches in length, with strong wings and legs and with bills slightly notched near the tip and supplied with strong bristles at the base. They are uniformly colored rather than streaked, the majority brownish or grayish, although blues, yellows and even reds are found in the plumages of some. The underparts are white, or at least lighter than the backs, and in typical species are more or less spotted. In species having unspotted breasts, the young in their juvenal plumage show the spots that have been lost by the adults, as in the robin and the bluebird.

But it is not for the brilliancy of their plumage that the thrushes are noted; it is for the richness and beauty of their songs. The world over, some member of this family surpasses all others in the appeal which it makes to the human ear. In Europe it is the nightingale, in eastern United States it is the hermit thrush, and in the western it is the solitaire.

Except during the nesting season, the thrushes travel in scattered flocks, frequenting the borders of woodlands but coming into gardens if they can find food. During the spring and summer this consists almost entirely of insects, but during the late summer and fall the various wild fruits form an increasing percentage Gardens having dogwoods and Virginia creeper are sure to attract the passing flocks of thrushes in late September or October, and in the South the mistletoe and holly sustain some species throughout the winter. The robin, the bluebird and the hermit thrush remain in southeastern United States for the winter, and the solitaire and the varied thrush in the southwest, but the veery, the olive-backed, the gray-cheeked and the woodthrush continue their journeys to Central America and northern South America.

Of all the thrushes, the robin is, of course, the best known, although in coloration it is so aberrant as not to be recognized as a thrush by many people. It was christened "robin" by the early settlers because of its general resemblance to the European robin, although the latter is a much smaller bird. It was probably originally a forest dweller, as it still is in some places, but like its European cousin, it has become accustomed to man and now builds its nest wherever it can find a sheltered ledge about the house.



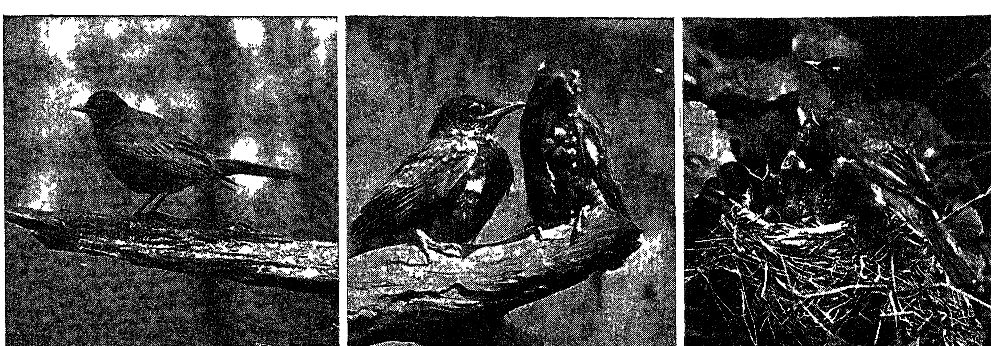
THE EUROPEAN NIGHTINGALE AND ROBIN

Its numbers have probably increased more than those of any other native bird in the United States, so that today it is undoubtedly the most abundant species throughout the country.

Another aberrant member of the thrush family is the familiar bluebird. With its blue back and chestnut breast, it is indeed one of the most beautiful birds of the countryside and well worth every effort to increase its numbers. It is quick to respond to hospitality, and in many localities has greatly increased because of the nesting boxes which have been put up for it. The western bluebird differs from the eastern in having the throat blue instead of chestnut and in having a brownish spot on the back. The mountain bluebird of Alaska and the higher Rocky Mountains has the entire underparts light blue, but it is quite similar in habits to the other species.

After the robin and bluebird, the next thrush to arrive in the spring, while the branches are still bare, is the hermit thrush. Being of a retiring disposition and frequenting woodlands rather than gardens, it is less often seen, although during cold wet spells, when food is scarce, it ventures close about the house and comes to feeding shelves with the chickadees and juncos. The hermit is a typical thrush with uniform dark brown upperparts and whitish underparts with dark spots on the fore part of its breast. The breast is less spotted than that of the wood thrush and more so than that of the veery. The hermit is easily distinguished from the other thrushes by its rufous tail, which it lifts slightly when it alights. It nests in Canada and in the hills and mountains of the northern United States above an altitude of 500 feet, placing its nest of mosses and grasses on the ground beneath a sheltering bough.

It is only on its nesting ground that its full song is heard and there usually early in the morning, toward dusk, or even in the dead of night. Then, when the woodland is silent save for the occasional ecstatic outburst of an oven-bird hurling itself above the trees, the clear tranquil notes of the hermit will move even the most stolid. Beginning low like the distant dripping of some cool spring, the singer runs lightly up the scale until it touches the highest notes. a still higher note, a trill and then silence. Soon the low liquid notes are heard again as the bird moves nearer and the song is repeated again and again, not hurriedly but with all the leisure and solemnity that a finished production requires. All nature is hushed and seems to listen to the voice that expresses so well the purity, the serenity, the mystery of the twilight in the forest.



COCK ROBIN'S FAMILY ALBUM

Father on the feeding log, Débutantes in their first plumage, And mother at home with the babies.

The illustrations in this chapter, except the two at the top of this page, are from photographs by A. A. Allen

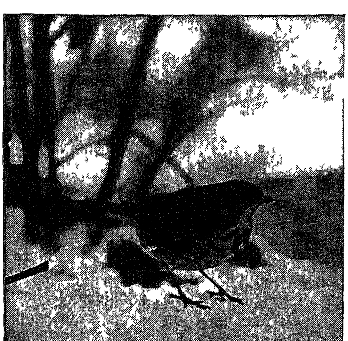
The wood thrush and the veery are but little inferior to the hermit in their songs and in most places are much better known, for they often take up their abodes in city parks or about shaded lawns. The veery requires moist woodlands with undergrowth in which to place its nest, but the wood thrush is often content in an orchard or along shaded streets. The song of the wood thrush is somewhat like that of the hermit but the phrases are shorter and the notes less clear. The veery's song, on the other hand, is quite different. Rich and clear like the songs of the other thrushes, it consists of a single continuous warble like the syllables, wee-o, wee-o, wee, we-o, given on a descending spiral.

The olive-backed and gray-cheeked thrushes are less well known than the others. Wintering in South America and nesting in the coniferous forests of the north, they are known in the United States only as transients in the spring and fall except in the mountains of New York and New England, where they nest at altitudes over 2500 feet. They are both uniformly darker than the other thrushes and can be distinguished from each other only in good light because in the olive-backed the eye ring and cheeks are washed with buffy. The sub-species of the gray-cheeked thrush which nests south of the St. Lawrence is somewhat smaller than the northern bird and has been named the Bicknell thrush.

The Townsend's solitaire of the Rocky Mountain region is similar to the hermit thrush in its habits, living alone in the coniferous forests whose silences are broken only by the beautifully clear notes of this bird. The solitaire is a dark, gray bird, about the size of a bluebird, with a white eye ring, white wing bars and white tips to the outer tail feathers. It builds a rough nest under a shelving bank and, unlike the other thrushes, which lay blue eggs, it lays grayish-white eggs spotted with brown.

THE ROBIN'S NEST IN THE ROSE ARBOR

The varied thrush is a strikingly marked bird of the northwest, ranging in summer from Alaska to the mountains of northern California and wintering from Washington to lower California. It is a bird about the size of a robin, rusty brown beneath, the throat crossed by a blackish necklace, and dark bluish-slate above. It is ordinarily a rather shy bird, dwelling in the spruce for-



OUR MOST MELODIOUS SONGSTER

A hermit thrush at a feeding station in winter.

Wood thrush feeding its young in a nest.

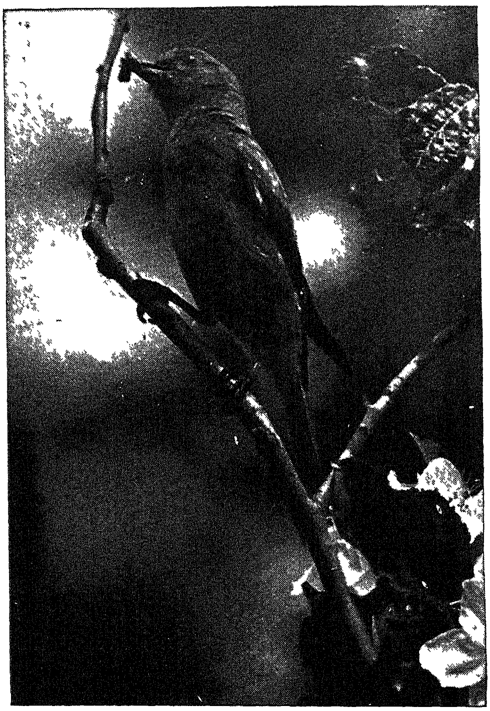
The veery thrush at its nest.

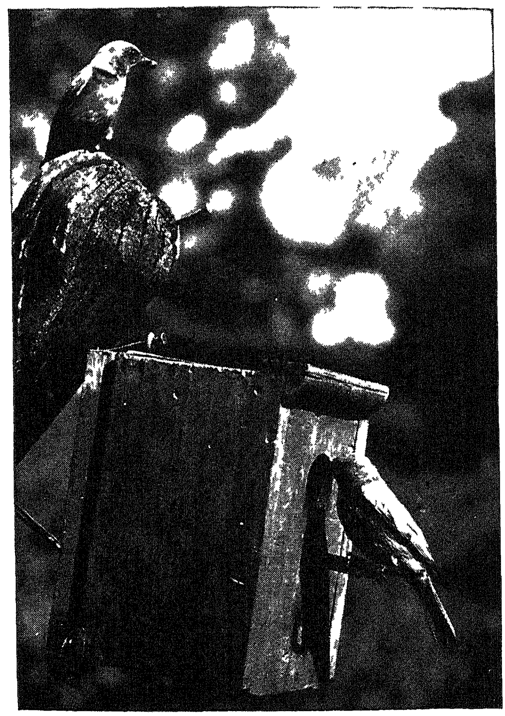
ests, but on its winter journeys it frequently comes into gardens where it can find the berries of the California holly or of the manzanita.

The Chickadees

Closely related to one another and formerly placed in one family (*Paridæ*), the nuthatches and the chickadees are associated in more than name, for after the nesting season, they gather in loose companies and spend the cold winter months together. Seeming to enjoy their society, other winter birds often follow these flocks so that when one hears the yank-yank of the nuthatches and the scolding chick-a-dee-dee of the chickadee, he can look also for the slender brown creeper winding its way up the bole of the tree, the downy and hairy woodpeckers, and the golden-crowned kinglet. Not only are they sociable among themselves, but they seem to have little fear of mankind and gather about suburban dwellings wherever food is offered them.

There are 241 species in the chickadee family, found in most parts of the world except South America and the Pacific Islands but most abundant in the northern hemisphere In North America there are but fifteen species represented, extending southward into the mountains of Mexico Of these, six species are known as chickadees, four as titmice, three as bush tits, one as a wren tit and one as a verdin All are alike in being small fluffy birds with long tails and short pointed bills. The chickadees are dull grayish birds, lighter below, with conspicuous black crowns and throat patches. The Hudsonian chickadees of the far north, which come southward in winter irregularly to northern United States, have the top of the head brown rather than black, and the mountain chickadees of the Rocky Mountain region have a white stripe over the eye, but all six species are easily distinguished by anyone familiar with the common chickadee.





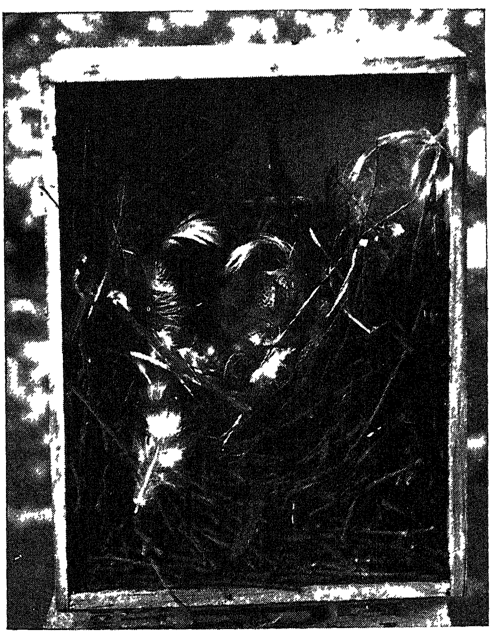
ANOTHER ABERRANT THRUSH

The familiar bluebird in the orchard.

A pair of bluebirds at their nesting box on a fence post.

The songs and call-notes of the different species vary considerably, but all have a family likeness. The scolding call of the common species gives the name to the family, for it is a clearly enunciated chick-a-

dee or chick-a-dee-dee. In other species it is less clear, more highly pitched or more nasal. In addition to this note, the chickadee has a song of two or three sweet whistled notes resembling the syllables phe-be or phe-be-be so exactly that amateur bird students are often led to believe that it is a phœbe calling. When trooping through the woods, the chickadees have a variety of conversational notes that are rather difficult to describe and when protecting their eggs or young against intrusion, they utter a hissing or sputtering sound.



THE INS AND OUTS OF A WREN'S NEST

Rough nest of the house wren inside the nesting box.

Young house wrens waiting for breakfast to be served.

The chickadees are friendly, inquisitive birds, and it is not only at the winter feeding stations that they become tame. They are always ready to answer an imitation of their phe-be call and will come flying through the woods to greet the traveler, perching on the branches above his head, sometimes even dropping to his shoulder or hovering a few inches in front of his face in a vain endeavor to discover the whereabouts of the other chickadee.

The titmice, as the name is now used, differ from the chickadees in having the crown feathers elongated in the form of a crest. The tufted titmouse of the East and the plain titmouse of California and Oregon are the best known species, the other two being Mexican, coming into the United States only in Texas and Arizona. The tufted and the plain titmice are uniformly gray, a trifle larger than the chickadees but with the same ways of flitting about the outer branches, hanging upside down, peering under the leaves, and examining the crevices of the bark. The loud whistled call of the tufted titmouse, peto-peto-peto, is one of the familiar sounds of the southern woodlands, while the tu-whit, tu-whit, tu-whit, of the plain titmouse is always associated with the live oaks of California.

The wren tit and the bush tits are browner birds than the chickadees, the wren tit being more or less wrenlike in its brown garb and its habit of holding its tail tilted upward. The bush tits are mere sprites of bird life, over half of their length of four inches being tail, so that their bodies seem scarcely larger than the end of one's thumb. In habits they resemble the chickadees with the exception that they build long purse-like nests of soft materials, hanging them usually in thickets of ash and willow.

The verdin is very similar to the bush tits in size and habits, but its whole head, neck and chest are bright yellow It lives in the mesquite valleys of the Rio Grande, the Colorado, the Gila and the Pecos rivers of the Southwest, where from the thorny bushes it scolds and sputters at every intruder

The Nuthatches

Like the chickadees the nuthatches (family *Sittidæ*) are largely confined to the northern hemisphere There are about 70 species of which only four are found in North America These are bluish-gray birds, brighter than the chickadees, with white or rusty underparts, and with the top of the head brown or black The chief characteristic of the nuthatches is their habit of climbing the trunk and larger branches of trees in search of insects, upward or downward with equal facility. Unlike the woodpecker they do not use the tail as a prop, nor are their feet arranged with two toes forward and two backward. Instead they have the ordinary perching type of foot with three toes forward and one backward Both the toes and claws, however, are of necessity much better developed than in ordinary perching birds. Certainly they seem to have no difficulty in spiraling about the trunks of trees, and in fact they have been known to sleep hanging head downward, clinging to the bark beneath a jutting limb They are lively little creatures, always on the move, peering at one from strange angles, and their contented yank-yank adds much to the cheerfulness of the northern winter. The name is supposed to be a corruption of nut-hack, derived from their habit of wedging nuts or large seeds into the crevices of the bark and then hacking them open

The white-breasted nuthatch is the commonest species and is found throughout the United States and Canada from the Gulf States to central Ontario, preferring open woodlands, roadsides and gardens. It is pure white beneath, except for the under tail coverts, which are reddish-brown, and bluish-gray above, the top of the head and neck being shining black. In the female the black is somewhat veiled with gray.

The red-breasted nuthatch nests only in the northern part of its range from northern United States to Alaska, but in winter it wanders as far south as the Gulf States It is somewhat smaller than the white-breasted species, having the entire underparts, except the throat, rusty and having a white stripe over the eye It has a partiality for pine trees but, like its white-breasted cousin, it comes freely to the window for suet and sunflower seed Its notes are similar but more nasal and are pitched higher, like the syllables yna-yna

The brown-headed nuthatch is confined to southeastern United States from Delaware and Missouri to Florida, frequenting the extensive pine forests It is smaller even than the red-breasted species and its notes are different from either of the preceding, a conversational pit-pit and a scolding dee-dee-dee being the most familiar

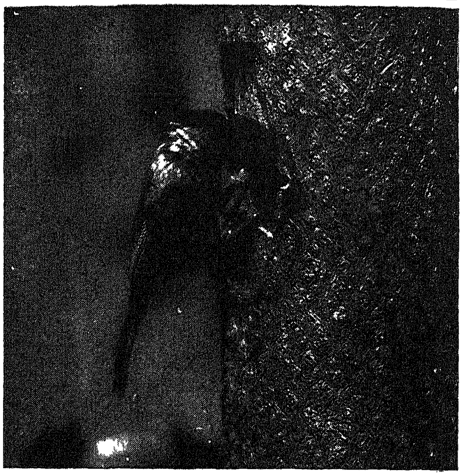
Very similar in appearance and habits but still smaller, measuring sometimes less than four inches in length, is the pigmy nuthatch of the Rocky Mountains.

The nesting habits of the North American nuthatches are much alike They usually select a knot hole in the trunk of a tree, occasionally a woodpecker's hole, and line it with feathers, leaves, wool, etc They lay from four to nine white eggs, which are heavily marked with brown The common European nuthatch has the curious habit of plastering up the entrance to its nest with mud until the opening is just the right size and the American red-breasted nuthatch usually decorates his with nodules of pitch as though to make it less attractive to squirrels and to other enemies.

The Kinglets

Sometimes following the winter flocks of nuthatches and chickadees but more often associated by themselves among the evergreens, one finds the kinglets (family *Sylviidæ*). There are but two species, the golden-crowned and the ruby-crowned, found in North America and they resemble very closely some of their European cousins. They are both tiny birds, smaller than the chickadees, olive green in general color with bright patches of color on the tops of their heads, which they display at will.

A TROOP OF FRIENDLY WINTER BIRDS



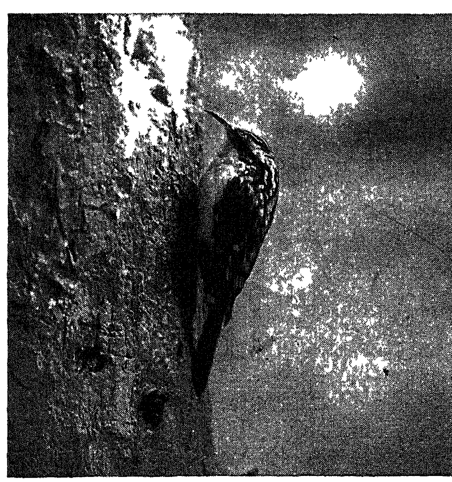
THE BLACK-CAPPED CHICKADEE

A FRIENDLY CHICKADEE TAMED BY FEEDING

WHITE-BREASTED NUTHATCH ATTRACTED BY SUET

NUTHATCH ABOUT TO ENTER ITS NEST IN A TREE

A RUBY-CROWNED KINGLET



A BROWN CREEPER ATTRACTED BY SUET

The ruby-crowned kinglet is the more migratory of the two, spending the summer farther north and winter farther south than the golden-crowned, and is seldom found in northern United States during the winter. They are nervous, energetic little birds continually flitting their wings and hovering at the tip of a branch in search of insects, but they have little fear of man and will often approach within a few feet. The golden-crowned kinglet does not have much of a song, just a few sibilant notes, but that of the ruby-crowned kinglet is surprisingly loud and melodious. Both species build more or less hanging nests of moss and fine strips of bark in coniferous trees and lay tiny cream-colored eggs spotted with brown.

The gnatcatchers, of the same family as the kinglets, and of which there are from fifteen to twenty species found in the New World, are mainly tropical, only three species finding their way north of Mexico and only one of these, the blue-gray gnatcatcher being well known. Like the kinglets it is a tiny bird but it has a longer tail and is colored bluish-gray above and white below with a little black on the forehead.

The Creepers

There are twelve species of creepers (family *Certhiidæ*) but only one, the brown creeper, occurs in North America. It is a slender brown bird about the size of the chickadees but entirely different in habits, although it likes to accompany them in their winter wanderings. In habits it is more like a tiny woodpecker, for it climbs about the trunks of trees using its stiff tail as a prop. It has a slender curved bill, however, and never drills into the tree for borers, but contents itself with such insects and eggs as it can find in the crevices of the bark. Its streaked brown back matches the bark so that it often escapes attention even though it is so lacking in fear that it will sometimes alight at the base of a tree within a few feet of one and spiral up the trunk in its characteristic manner. It usually selects some projecting piece of bark and builds a nest of twigs and moss and bits of fiber beneath it. Its song is not often heard. for it consists of but a few weak notes.

The Wrens

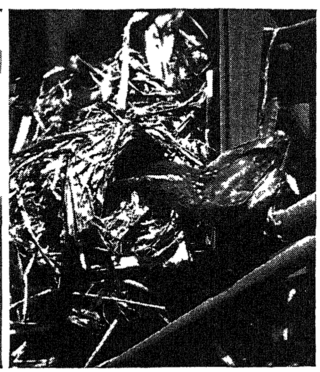
Ages ago there dwelt in northern Africa and along the Red Sea certain tribes of herdsmen who made their homes in the caverns which the sea had gnawed in the rocks. They were hole-dwellers and so the Greeks called them "troglodytes". This alone could have prompted the name (*Troglodytidæ*) for the great family of wrens, for surely there is no other comparison between these prehistoric, carnivorous shepherds and the little, energetic, brown birds composing the wren family. There are about 260 different kinds of wrens, the majority being found in the tropics of South and Central America. Between thirty and forty are found in the Old World and only fourteen in the United States and Canada.

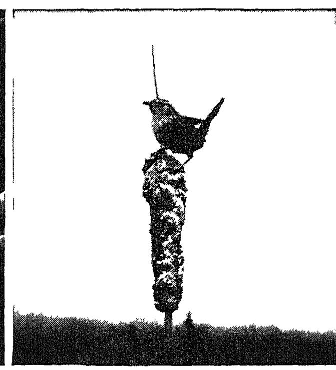
In spite of their numbers, they are remarkably uniform in their plumage, wearing browns and grays in very inconspicuous patterns. They are, with few exceptions, very small birds, seldom exceeding five or six inches in length, with rounded wings and short tails which they characteristically hold erect or even tilted forward over the back. Their small plump brown bodies and their habit of haunting brush piles or sneaking along the ground gives them an exceedingly mouselike appearance. In fact, were it not for their inquisitive ways and their petulant voices, wrens would seldom be seen, but as it is, one cannot pass their retreats without being surveyed from every side and without being the subject of their loud invective calls.

When not alarmed, the male seeks some exposed perch, where, with drooping tail, he gives vent to his feelings in a voice of surprising volume and sweetness, for, with the exception of the cactus wrens, the whole family is famous for the brilliancy of its songs. Even the familiar loud, bubbling, gurgling song of the house wren sinks into insignificance when compared with the ringing songs of the Carolina and canyon wrens or the roundelay of the winter wren. As in most birds, the song is usually confined to the male, but there are certain tropical species which have the delightful habit of singing in duets.

The house wren is the commonest and most widely distributed of all the family, some form of it being found throughout North and South America from Quebec to Argentina. It is uniform dark brown above, faintly barred with black, and brownish gray below. It is smaller than the Carolina wren, which is more rufous, having a light line over its eye; and it is larger than the winter wren, which is more heavily barred and darker beneath, but it resembles considerably the Bewick's wren. This bird, however, has a light line over its eye like the Carolina wren and light spots on the corners of its tail. So similar are all of the wrens to one another in size and color that it is much easier to identify them by their songs, which are distinctly different.


A HOUSE WREN SINGING


A LONG-BILLED MARSH WREN


A SHORT-BILLED MARSH WREN

Both the house wren and Bewick's wren are fond of the habitations of mankind and are quick to avail themselves of nesting boxes put up for them, the house wren from Quebec to Virginia, the Bewick wren from central Pennsylvania to South Carolina. They can be attracted even to the heart of large cities more successfully than any other bird because the opening in the nesting box need not be larger than an inch in diameter and this will not admit sparrows or starlings which have done so much toward driving the hole-nesting species away from the cities by usurping all the available nesting places.

The winter wren and the Carolina wren are woodland species but their breeding ranges do not overlap except in the Alleghanies. The winter wren is a Canadian species while the Carolina wren is a southern bird which occurs only occasionally as far north as New York and New England. In the fall, however, the winter wren migrates southward, some as far as Texas and northern Florida, and, at this season, all four kinds, as well as the two species of marsh wrens, may be found in the South.

The long-billed marsh wren is the commoner of the two latter, frequenting the cat-tails and sedges of the marshes bordering lakes, creeks or sloughs, where its incessant song will always be heard. Even during the hours of darkness, when most birds are quiet, the marshes will often resound with their chorus. Often the wrens seem to be carried away by the exuberance of their own songs and, springing from the flags, they seem actually to explode upward. With their feathers shaken out, their short wings vibrating, their cocky tails tilted far forward, their plump little bodies look like animated cotton balls.

The short-billed marsh wren is much yellower in general appearance than his dark long-billed brother and is seldom found in the deep water marshes, preferring the sedgy borders of such or even meadows. Its song is little more than a repetition of its call, like the sound produced by striking two pebbles rapidly together, ending with a grating sound.

In the arid regions of the West dwells the largest and most unwrenlike of all the wrens, the cactus wren. It is a gray bird with a white spotted breast whose large retort-shaped nests are one of the most characteristic sights of the cactus country. Its song is the least musical of any member

of the family, although it is given in characteristic wren fashion with the tail drooping and the head thrown back.

In the dry rock-bound regions of the West, where most bird life is scarce, there lives the rock wren, whose curious tinkling song is one of the few redeeming and comforting features of many of the desolate rock slides of the mountains.

In the canyons, it is the song of the canyon wren that so frequently causes the rocks to reverberate with wild ringing notes. The "bugler" he is sometimes called, but a tiny bugler indeed, less than six inches in length and so inconspicuous that but for his white throat he would escape unseen.

THE CUBAN MOCKINGBIRD

The Parkman wren and the Vigors wren of the Pacific Coast region are the western representatives of the eastern house wren and Bewick wren respectively. The common wren of Europe and the British Islands, or "Jenny-wren" as it is there called, is a species very similar to our winter wren both in song and habits except that it more often frequents gardens.

The Mockingbirds

What the nightingale is to Europe, the mockingbird (family *Mimidæ*) is to our Southern States. There is this difference, however, that the nightingale has but one beautiful song while the mockingbird enriches his repertoire with the notes of many other birds. In fact, there is a record of one mockingbird which imitated 32 different species during the course of ten minutes continuous singing. All individuals are not good mockers, however, and perhaps the majority confine themselves to their own brilliant notes. And brilliant their songs are, for the mockingbirds have marvelous technique, and while some people complain of their lack of feeling, others declare that they excel even the nightingale and the American thrushes in their emotional outbursts. They do not seek the deep forest, and perhaps for this reason their music is less appreciated. "But," says Dr. Frank M. Chapman, "listen to him when the world is hushed, when the air is heavy with the rich fragrance of orange blossoms and the dewy leaves glisten in the moonlight, and if his song does not thrill you then, confess yourself deaf to nature's voices."

The mockingbird is a slender ashy-gray bird about the size of a robin with white marks in the darker wings and tail. It is found about bushy pastures, the scrubby borders of woods as well as about gardens, or, indeed, wherever there is a thicket in which to hide and an exposed perch from which to sing. In some places along the Gulf of Mexico it is the most abundant bird, and its rich songs on every side drown out all the lesser bird voices of the vicinity. The nest, which is a rather bulky structure of sticks and straws, rags and paper, is lined with rootlets and placed in a thick bush, an orange tree, a yucca or even on the vines of the porch. The eggs are greenish-blue rather heavily marked with brown.

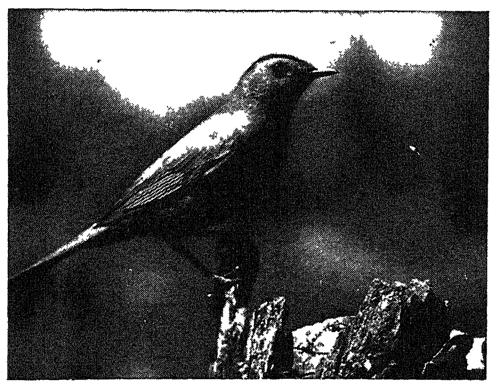
There are over sixty species in the mockingbird family, only eleven of which are found north of Mexico. One of these is the true mockingbird, one is the catbird and the rest are called thrashers. The catbird resembles the mockingbird in being a long, slender, gray bird, but it differs in being darker and in not having the white bars in the wings and tail. Its only marks are a black cap, black tail and reddish-brown under-tail coverts. It gets its name from the harsh catlike notes with which it scolds every intruder and with which it ruins an otherwise melodious song. Some catbirds are much better singers than others, many learning to imitate the notes of other birds with such skill as to gain for them the name of northern mockingbirds; but all of them, sooner or later, interrupt their musical refrain with harsh mewing notes.

Catbirds are either very sympathetic to the troubles of all the bird world or very inquisitive, for whenever a bird is in difficulties and gives an alarm cry, all of the catbirds of the neighborhood assemble to stare and to scold at the disturber. In the defense of their own nests, they are seldom excelled for bravery, for be it cat, squirrel, snake or man, the intrepid birds fluff out their feathers and fly at the enemy with loud cries, pecking with their bills and buffeting with their wings in attempting to divert attention from their treasures. The catbird always nests in the densest thicket, thorny bush or tangle of vines that the neighborhood affords and the nest resembles that of the mockingbird but the eggs are deep greenish-blue without spots.

In some places in the South the catbird is regarded with suspicion and thought to rob the nests of other birds, but in the North it is everywhere a favorite and no stigma is attached to its name. It is very largely insectivorous and therefore beneficial, although, together with the robin and the waxwing and many other birds, it shows a partiality for cherries and other small fruits in their season. Where mulberries and wild fruits are available, the cultivated varieties seldom suffer.

The thrashers, numbering about twenty species, are the largest of the mockingbird family. Their center of distribution is in southwestern United States and they extend southward through Mexico and westward through southern and lower California. Only one species, the brown thrasher or "brown thrush" as it is sometimes called, is found east of the Rocky Mountain region. It occurs throughout the East as far north as Quebec and occasionally somewhat farther. The brown thrasher is often confused with the wood thrush, although it differs in its much longer slightly curved bill, its long tail and its streaked rather than spotted underparts. It is a shy bird, much more often heard than seen, for it keeps to the undergrowth where it scratches among the leaves on the ground or digs holes with its bill in its search for larvæ. The sound produced as it apparently blows the soil from its nostrils is an almost animal-like snort. When singing, the male mounts to the topmost branches of a tree, from which its loud ringing notes can be heard for long distances. The song is a rich ringing medley, and though limited in its range and confined to one air, it rivals the mockingbird's in the exuberance of its tones and the perfection of its execution.

Occasionally the thrasher lives about gardens, especially if some effort is made to develop a tangle of shrubbery in which it can find seclusion and safety from enemies. Like the mockingbirds and catbirds, it will come to a food shelf for suet and crumbs and sometimes becomes quite friendly. The thrashers are equally ferocious in the defense of their nests, which are built in the heart of a thicket or on the ground beneath a tangle of vines, and they do not hesitate

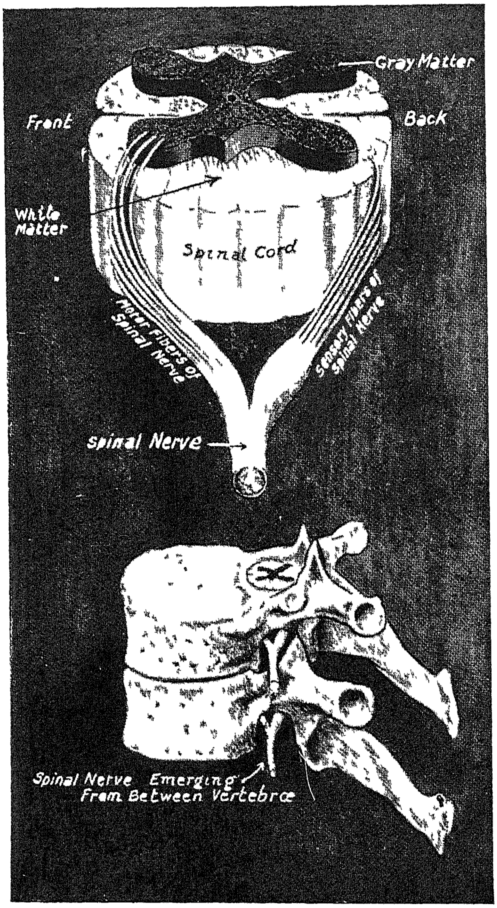


CATBIRD ON A FEEDING LOG

to peck and scratch one venturing too close. The nest resembles those of the catbird and mockingbird, having an outer layer of sticks and a lining of rootlets, but the eggs are rather slender, grayish in color, finely and evenly speckled with brown.

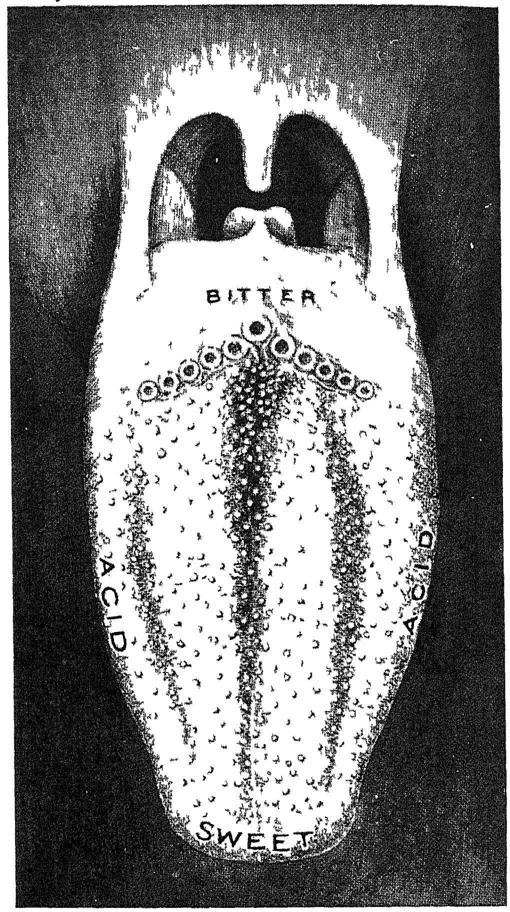
The curve-billed thrasher of Texas and New Mexico, the Palmer thrasher of the cactus deserts of Arizona, the California thrasher of the Pacific Coast region and the Crissal thrasher of the whole Southwest are about the size of the brown thrasher but are less strikingly marked, being uniformly brown or gray with few streaks. The sage thrasher is a somewhat smaller bird, appearing like a small mockingbird with a streaked breast. It is one of the commonest birds of the sage-brush country and has much the same habits as the other members of the family.

MAN'S SENSES OF TOUCH, TASTE AND SMELL



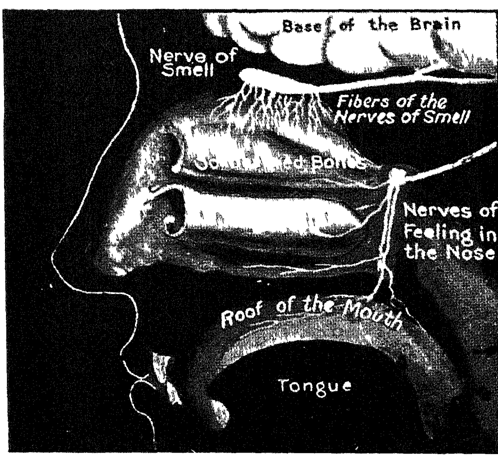
HOW THE FIBERS RUN INTO THE SPINAL CORD ON THE WAY TO THE BRAIN

The lower drawing shows how the spinal cord rests in the backbone, and (above) how the sensory fibers pass into the spinal cord, whereas the motor fibers pass out of it.

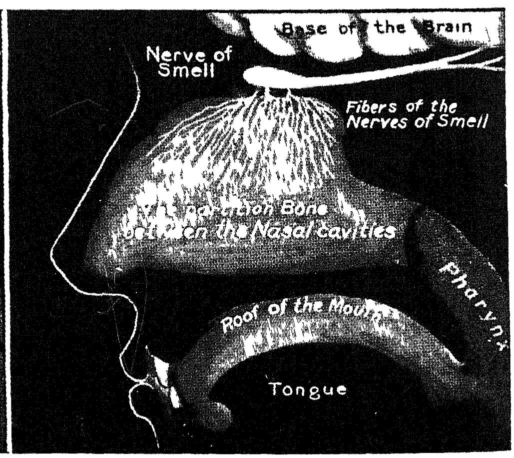


THE AREAS OF THE TONGUE IN WHICH THE CELLS OF TASTE ARE DISTRIBUTED

The tongue is covered with various types of taste buds most of the distinct types that appreciate the sweet, the acid and the bitter being found in the areas marked on the diagram



THE OUTER SIDE OF THE NOSE, SHOWING THE NERVES OF SMELL AND FEELING



THE INNER PART OF THE NOSE, SHOWING THE FIBERS FROM THE OLFACTORY BULB

MAN'S LESSER SENSES

Touch, Smell and Taste, and Their Seats in the Skin, Nose and Tongue

THE GATEWAYS OF SENSATION

STUDENTS of Bunyan's "Mansoul", are acquainted with the idea of the soul, or *psyche*, of man as having "five gateways of knowledge", or avenues of sensation by which the mind makes the acquaintance of the outer world. Modern science may not assent to this limitation of the number of our "gateways of knowledge" but it is convenient to take them in something like the old order, for these five senses are well defined, and each of them has a definite sense-organ, situated at the end, or ends, of its special nerves, and constructed for the reception of certain special kinds of stimuli. Vision, hearing, touch, taste, smell, obviously correspond to five definite "gateways" — eye, ear, skin, tongue and nose.

Of these "five senses", two are preeminent on account of their practical value, their range of capacity, their subtlety of employment, the perfectly astounding complexity of their respective end-organs and the psychical depths to which they are capable of leading. These are, of course, the eye and the ear, to which two preceding chapters of this section have been devoted. In the hierarchy of the senses these two stand co-equally first. The body of man has largely devoted itself to the construction of the machinery by which the possibilities of these two senses could be developed to the utmost. The skin or the tongue of man shows little, if any, superiority in structure to that of many humbler animals, and his nose is clearly degenerate, but the construction of his eye and ear is unexampled for delicacy, and for the extent and the richness of its nervous representation in the cortex of the brain. The evident reason is that these gateways open upon a far more valuable and varied range of possible knowledge, and that the apparatus for receiving this variety of knowledge has been devised accordingly.

We are therefore right to call touch, smell and taste the lesser senses, as compared with vision and hearing, but this is not to say that they are not worthy of careful study for they contribute many important ingredients to the sum total of our mental life; and the first, in particular, has special claims to respect, partly on account of its antiquity, and partly because several distinct senses are concealed under the name of touch, though all have their special sense-organs in the skin.

The various sensations which have their seat in the skin are usually called the cutaneous sensations, and the best and most scientific way in which to study them is by direct observation and experiment upon one's own skin. Science affords few better illustrations of the contrast between what we think we know of familiar things and what they reveal when they are seriously studied. Most of us would say that we knew all there was to know about the feelings of which the skin of our hands was capable, but the reader will shortly decide for himself whether that is so.

Within recent years it has been proved that our cutaneous sensations are not less than four in number. They may be more, and we shall perhaps see that there is reason to suppose so, but as to the existence of four distinct senses at least there is no doubt, nor as to the existence of a corresponding number of special areas, organs and nerves in the skin.

We think of the skin as a continuous covering, all of a piece and all the same. But if it were so constructed that its different parts had different colors, we should see it as a kind of tiny mosaic of at least four distinct colors — say, black, white, red and green — all dotted over the surface of our bodies; and in this case each color, wherever a spot of it occurred, would indicate a particular form of sensibility which could be felt in all spots of that color, but in no others. The problem for the skin has been to provide the mechanism for these four senses, everywhere at once, so that every part of the skin should be able to serve the needs of all of them. Strictly speaking, that was an insoluble problem, for one kind of apparatus is required for touch, another for temperature, and another for the sense of pain (to take these instances without further criticism for the moment); but the problem has been practically solved by making the respective spots exceedingly small, and mixing them up very thoroughly, so that, though no one spot of skin can really feel, say, both pain and pressure, yet the spots are so tiny and so closely packed together that it is as if the whole skin could feel everything that is required.

The different forms of sensation felt through the skin

This, together with the fact that no external indication like difference of color is there to help us, explains how it is that only lately have men discovered the simple facts which have been under and on their own noses ever since men existed at all. According to the best authorities of the present day, the four cutaneous sensations between which the whole surface of the skin is divided are the sense of touch or contact or light pressure, the sense of heat, the sense of cold and the sense of pain. No doubt we are at first inclined to protest, because the different spots of skin concerned lie so close together, and are so tiny, that under many conditions what we feel, and feel as if it were single, is really a mixture of two or more of these senses. Painful heat and painful cold are obvious instances of this, to say nothing of the apparent fact that sense of heat and cold is all one; yet it can be proved that these various senses are really distinct in every way. The local proof, in the skin itself, will be laid before the reader shortly, but first we must briefly refer to another kind of proof, derived from the study of nervous structure and nervous disease, which has long foreshadowed the recent discoveries regarding the skin itself.

Though we have carefully discussed the brain, very little has yet been said here about the spinal cord, the downward continuation of the brain into the spinal column, though, from the historical point of view, it is more correct to describe the brain as the upward expansion of the spinal cord into the cranium. The spinal cord contains some gray matter, some of which is concerned with motion and some with sensation, and we have seen that this gray matter is involved in what is called reflex action. The rest of the spinal cord consists of white matter or nerve-fibers running up and down its length. This white matter consists of a large number of quite distinct "tracts", as they are called.

The experimental value of accidents to the human body

One tract or bundle of fibers will be conveying impulses downwards to the muscles from the brain, another will be conveying impulses upwards from the skin, and many other parts of the body, to the brain, and so forth. Various forms of disease, and such accidents as fracture or dislocation, or bullet wounds, etc., have made and still make a variety of "experiments" upon the spinal cord, injuring it in part, so that certain consequences follow; and in such ways as these it has been possible to distinguish a large number of tracts, and to discover their special functions. Thus there is a well-known though rare disease of the spinal cord in which the accumulation of fluid within its central canal brings a fatal pressure to bear upon certain strands or tracts in its substance, and we sometimes find that the patient, though he can appreciate touch and heat and cold, is entirely insensitive to pain. A pin is felt to touch him, but does not hurt him.

Discovery of the different fibers that make up the spinal cord, and their uses

Such discoveries as this have led us to the knowledge that there are totally distinct tracts in the spinal cord, with distinct connections and distributions in the brain, which nevertheless all serve the skin; but while pain, as we loosely but conveniently say, runs up certain fibers and only up those fibers (so that, if damaged, pain cannot be felt), heat runs up others, cold runs up still other fibers and touch up yet other fibers. So far as the spinal cord is concerned, these four senses are thus just as distinct as are the senses of hearing and vision, each of which has its own special tracts of nerve-fibers in the substance of the brain. And just as nervous disease or accident or certain poisonings, such as nicotine poisoning, may affect the visual tract only, or the auditory tract only, so disease or accident or poisoning may affect the heat fibers or the pain fibers only in the spinal cord. All this is unquestionable evidence as to the justice of our claim that the skin, though it appears to be only a single thing, is yet the seat of four distinct senses, which on their much humbler plane have as good a right to be distinguished as have vision and hearing. At this point, however, the judicious reader will ask whether we can also point to the brain and say that there upon its surface is the center of touch, and there the center for pain, etc., just as we can point to the visual and auditory centers respectively.

Here it must be admitted that our knowledge is as yet inadequate. The problem of "cerebral localization" is still very far from solution in regard to the various cutaneous sensations. Hitherto the evidence seems to indicate that they are all represented in the same area or areas of the cortex, just posterior to the one which is concerned with voluntary motion.

Skin a patchwork, in which different sensations are felt by different parts

But, in the judgment of the present writer, this fact is perhaps not so disconcerting as is generally thought. Until we examine the skin very closely, we fancy that the whole of the skin is capable of feeling all four cutaneous sensations, the fact being that the skin is a patchwork so closely assembled that though only one-fourth, say, of the skin can really feel any one of these sensations, yet for practical purposes it is as if all four were represented everywhere in the skin. The suggestion may be made that a corresponding state of things may be found to exist in the cortex when we are able to examine it microscopically and chemically in a corresponding fashion to that which we are about to describe for the skin. It may then be found that the cortical area concerned with these senses is itself an assemblage of parts, thoroughly well mixed, so to speak, each of which has nevertheless its own specific function and none other, just as we saw in the case of the nervous apparatus of sight or hearing, which replies in its own unique way to *any* stimulus to which it replies at all. If so apparently simple a structure as the skin can really be an assemblage of (at least) four distinct kinds or parts, each with a special function, there is no difficulty in believing that the area of the cortex, which deals with the cutaneous sensations, has a corresponding complexity. It has millions enough of nerve-cells, of many different kinds, to support such an assumption; and it may yet be shown, for instance, that the cells in one layer of this area are concerned with the impulses coming up through the pain-fibers from the pain-spots in the skin, while the cells in the layer above or underneath it may be similarly concerned with touch or heat or cold. But exact knowledge at this point is still to be found.

Some spots on the skin sensitive to cold and others not

Let us now return to the skin, and try to appreciate the experimental evidence which proves that it is an anything but crazy patchwork of tiny areas, each one of which can receive and transmit a special kind of stimulus and that alone. We cannot do better here than quote the directions to the elementary student given by Dr. William McDougall, the author of one of the best textbooks for that purpose:

"Let him touch gently a hair on the back of his hand. This will excite light pressure-sensation, for the roots of the hairs are surrounded by the minute sense-organs of the pressure sense. Then let him choose a small area of skin devoid of hair — say, the palm of the left hand — and prod it gently with the end of a moderately fine hair, working over it systematically. He will find, if the hair used is of appropriate length and rigidity, that some spots readily yield pressure-sensation, while others are insensitive to this gentle stimulus. Let him mark these spots with an aniline pencil. Then let him take a blunt metal point (or a blunt pencil-point will serve the purpose), and work over the same area, drawing the point in close-set parallel lines across the surface. He will find a number of spots which, when touched, give distinct sensations of cold, all other parts giving no such sensation.

Some spots that are sensitive to heat and others that are not

"Working over the area again in similar fashion with the blunt metal point warmed to about 45° C., he will find a third set of spots from which alone sensation of heat is evoked Lastly, let him take a short horse-hair, mount it in the split end of a match-stick, cut it across obliquely half an inch from the handle, and then prod over the same area of skin. He will find that smarting or pain-sensation is evoked at a fourth set of points, and not elsewhere."

One concluding and conclusive experiment is worth making here. Let us recall the famous doctrine of Johannes Müller, that the sensory apparatus of each sense is *specific*, so that if the ear be excited by sound or inflammation, or the eye by light or a fist, the results must be hearing and vision respectively. If such a doctrine is to be proved, we should find it possible to excite certain senses by something other than their natural stimuli, and yet produce the customary sensation. This we have already seen to be true of various senses, which can be excited by electricity. Thus the eye can be induced to *see* in the dark by means of electricity.

If the tongue be stimulated by an electric current, the result is taste, and the particular quality of taste experienced will correspond to the particular and specific tendency of the part of the tongue excited. Similarly, when an electrical current traverses the mucous membrane of the nose, we experience sensations of smell. But the skin affords us a more striking example than any of the discovery of Müller.

The curious fact that heat on a cold spot of the skin feels cold

In the series of simple experiments above described, we have already ascertained and localized the "cold spots" of the skin, those, namely, where alone sensations of cold are experienced. We saw, also, that the skin contains heat-spots, which we identified by the use of a metal point made fairly warm, though not so warm as to complicate the case by also exciting the pain spots. What will now happen if we apply this warm point of metal to a "cold spot"? If the experiment be delicately and accurately made, we find that a sensation of *cold* is experienced as a result, even of stimulation by heat. This is known as paradoxical sensation of cold. A paradox is an apparent absurdity, and there is no better instance of one than this production of the sensation of cold by the application of heat to a sensory organ which was specifically constructed so as to give us the sensation which we call cold, and no other. The parallel to the other senses is complete, and the law of Müller is strikingly vindicated.

Finally, it remains to ask whether there are special organs in the skin which serve these special sensory functions. Careful microscopic investigation shows us some peculiar structures, the Malpighian and Pacinian corpuscles and others, named after their respective discoverers, which can be found notably in the tips of the fingers, in the sensitive tongue and claws of such birds as the parrot, and elsewhere. But all the structures which anatomists have been able to discover in the skin of man or any of the lower animals seem to be exclusively concerned with the special sensation of touch or pressure.

The difficulty of tracing the separate areas of the four senses of the skin

Though we can identify hot, cold and pain spots by the simple method above described, the microscope cannot identify any special structure in the skin according to the various functions of the various spots Nor can much be said as to the functions of the ridges on the skin of the fingers in this respect.

Herbert Spencer made the very reasonable suggestion that the special structures associated with touch would be found to be arranged along these ridges, but in point of fact the "touch-bodies" were found to be more abundant in the grooves between the ridges, and the only function which has yet been certainly attributed to these ridges is for purposes of criminal identification! But though we cannot describe, in the skin, special organs like the eye and the ear, or even organs so distinct as, say, the rods and cones of the retina, at any rate we have definitely proved that four distinct senses reside in the skin, that each has its own areas, its own nerves and its own path in the spinal cord; and we may yet be able to say that each also has its own area, or its own host of tiny areas, or its own layer of nerve-cells, upon some part of the cortex of the brain.

Taken as a whole, the four cutaneous sensations are obviously of very high importance, which we may specially define, from the standpoint of man's place in the world, as protective rather than instructive.

The lower plane of the protective skin-senses compared with the eye and ear

Doubtless they are in part instructive, and are to be regarded as a fourfold "gateway of knowledge", but when we compare them with the eye or the ear, which afford us such a limitless range of information, about the structure of the stars, and the thoughts of our fellow-beings, we see how clearly the cutaneous sensations belong to a lower plane, and may be defined as primarily protective, and secondarily instructive, in function. The fact that something hurts us is useful not so much in teaching us its nature, which is probably very simple and only has the quality of coming to a sharp point or edge, as in causing us instantly to withdraw from what may injure our life and health, and to avoid such a thing in future If we come to study the nature of the pin or the knife in any deeper way, we require to use the eye, which is for instruction, while the skin is for the preliminary and essential but lower function of protection. Similarly, our sensations of pressure and heat and cold are essentially protective in their utility.

The four qualities of sensation noticeable in taste

The sense of taste has its end-organ in the tongue. A few taste-buds, as they are called, can be found scattered upon the soft palate and sides of the throat, and are not to be despised by anyone who is so unfortunate as to be deprived of the tongue, but for our present purpose they may be ignored. When the covering of the tongue is studied microscopically we find various types of taste-buds, evidently comparable to the touch-bodies in the tips of the fingers, and to those touch-bodies which are also found in the tongue itself. The distribution of these taste-buds, which are to the sense of taste what the eye is to vision, or the inner ear is to hearing, can be shown to correspond to the particular aptitudes of the various parts of the tongue. In the case of the eye we saw that there are probably four distinct or elementary qualities of sensation which can be excited through it. In the case of the skin the number was also four. In the case of the tongue the number happens to be four again. Of course, there is no reason to suppose that this is any more than a coincidence, but it is at least a mitigation of the task of memory that eye, skin and tongue correspond to four elementary sensation-qualities apiece.

Do sweet, sour, bitter and salt exhaust our elementary sensations of taste?

The reader should really consider his own recollections before he proceeds. At first, remembering the almost innumerable articles of diet, meat, fruit, vegetables,

salts, sauces, wines, spirits, medicines and what not which have assailed his palate, he will confidently say that to limit our varieties of taste to four is truly ridiculous. But on further consideration he will probably agree that what he has been reviewing is scarcely so much a variety of tastes as of flavors; and he will readily admit, if he has ever had a bad cold, that flavor is a matter of smell as well as of taste. Let him now try to exclude all questions of odor from his recollections, and confine himself purely to taste.

How many different kinds of pure taste can he name? Here, again, as in the case of the eye and the skin, we must not be so positive as to exclude the possibility of further refinements of our knowledge, but it is probable that sweet, sour, bitter, and salt really cover all our elementary taste-sensations. They are as genuinely distinct as the various sensations which have their end-organs in the skin. Thus, as we have already hinted, if an electrical current be passed through the tip of the tongue, the sensation excited by it is that of a sweet taste. If it be passed through the upper part of the back of the tongue, the sensation excited is that of a bitter taste. Plainly, the law of Müller holds good here as elsewhere. It may be noted, as further anatomical confirmation, that different sensory nerves supply the front and back parts of the tongue respectively, and the taste-bulbs found in the various parts of the tongue, tip, edge and back part of upper surface, are largely distinct in structure. There is a good deal of intermixture among them, no doubt, but the separate sensations are kept much more to themselves than in the case of the skin.

An analysis of the taste of lemonade into simple "notes"

Anyone can prove for himself that sweets taste best in the front of the mouth near the tip of the tongue, and children who are not worrying about appearances have no hesitation in eating sweets in a fashion which bulges the lips forwards, not in order to be rude, but because sweets taste best there. But, on the contrary, when we amateur-wise swallow a dose of quinine, and it first encounters the tip of the tongue, we think that really it is not half so bad as we expected. Then we swallow it, or try to, and plaster the back of the tongue with it, whereupon we discover that our worst anticipations were inadequate.

Except when we make such experiments, and in a few other cases, our sensations of taste are usually excited in various combinations simultaneously. This largely explains how it is that, though we have only four elementary qualities, we can distinguish so many different tastes. Lemonade tastes like lemonade, for instance; we can identify and remember it. But if we consider our sensations in this case, even the least gifted of us will be able to perform a feat parallel to that of a musician who hears a chord, and can identify the various notes which compose it. We can clearly identify two simple "notes", so to say, in the "chord" of taste which we call the taste of lemonade. One of them is sweetness, and the other is acidity. If we care to experiment, applying the lemonade carefully to the tip and the edges of the tongue in turn, we can bring out these constituents of its taste with more prominence; and if a bitter ingredient has been included in the brew from the pips or the peel the back of the tongue will identify that as a third ingredient of the "chord" of lemonade thus "modulated".

Points of similarity between the senses of touch, taste and smell

The end-organ of the sense of smell is constituted by a certain restricted portion of the mucous membrane or lining of the nose. We should be astonished at the extent of this lining if it could be spread out flat before us, but its great area is mostly concerned with the purification and modification of the air before it enters the lungs. The nerves of smell, or olfactory nerves, only run to a relatively small area of this mucous membrane in the upper part of the nose — a position which explains the fact that we smell much better when we "sniff" for the purpose, for sniffing carries the current of air upwards to the olfactory membrane, as it is called.

For let us particularly note that taste and smell, which are often called the chemical senses, are closely allied to the sense of touch in the skin, with which they are doubtless connected historically and evolutionally, in that actual *contact* is a necessity for their action. The eye is affected by light-waves, and the ear by sound-waves, but the tongue and nose are not affected by any kind of waves, though the swimmer who inhales at the wrong moment may be of a different opinion. The tongue and the nose are affected by contact. If we suppose that this is not true of both of them — for though one cannot taste at a distance, one certainly can smell at a distance — we have to learn that smell depends upon contact no less than taste does. Actual atoms or molecules of the odorous substance must enter the nostrils and come into actual *contact* with the olfactory mucous membrane before the sense of smell can be aroused.

A grain that will perfume a room for twenty years

This is indeed one of the classical illustrations of the almost infinite divisibility of matter, and the minuteness of the atoms of which it is composed, for a single grain of musk will perfume a room for twenty years; and it has been proved that in this and all such cases actual portions of the odorous substance must be in process of emission and distribution all the time, if it is to be smelled. The fact clearly extends our idea as to the number and the minuteness of the atoms of which the grain of musk, or whatever it be, must be composed. The special point for us here, however, is that when we perceive the odor of anything "at a distance", we are not responding to vibrations it has set up in the ether or the air, as if it were a luminous or sonorous body, but are experiencing a "chemical sense", due to the chemical action of physical particles — which may be gaseous, liquid or solid — from the body in question.

There are many puzzling aspects about the sense of smell, and it may be suggested that the obscurity and uncertainty of outline which the facts of this sense present are partly due to the circumstance that it is decadent in man, and suffers from those marks of decadence which show themselves in obscurity and inconstancy in the case of other organs and functions.

The inadequacy of the study of flavors and the trained nose

The best psychological observation has hitherto failed to analyze the sensation-qualities of this sense as we have succeeded in doing in the case of the eye, the skin and the tongue. This is, no doubt, partly due to the fact that we cannot test different parts of the olfactory mucous membrane as we can test the different spots upon the skin or the tip, edge and back of the tongue. In the nature of the case, we have to apply our stimulus to the whole surface at once. Also, it is difficult to find suitable subjects to study, because individuals in whom this sense is well developed are comparatively rare, and such people as gourmets or wine or tea tasters are not always readily accessible in psychological laboratories.

No doubt a thorough study of the sensory discrimination of such people would add much to our knowledge of the subject. At present the best we can say is that different odors seem to vary in complexity, and that the trained nose can detect certain simpler elements in what seem to the less-trained nose to be simple odors, such as the flavor of a sauce, or of a blend of tobacco or tea or coffee or wine. It need hardly be pointed out that the flavor or bouquet of a great many pleasant things for which we thank the sense of taste is readily dependent upon the nose, and taste plays a quite subordinate part in our enjoyment, as those who are deprived of the sense of smell can attest.

It seems probable that even the degenerate olfactory sense of man includes, at any rate, several more varieties of sensation than his tongue can display. Some physiologists form a classification of scents or odors which appears to reduce them to about eleven groups, the members of any one of which resemble one another more than do the members of any other. Profoundly interesting and difficult problems

in what may some day be called psychological chemistry are raised when we try to establish relations between the members of these various groups in terms of chemical composition. We find that, just as most substances built after a special plan and known to the chemist as sugars are sweet, so most of the volatile oils which are derived from turpentine and resemble it in composition have a similar flavor. Thus we speak of ethereal oils, aromatic substances and so on, which are allied chemically and also allied in the class of olfactory sensation which they induce. This is very conspicuous in the case of the aromatics derived from benzene and the terpenes.

What will be the effect of chemical study on the sense of smell?

The future will, no doubt, be able to say far more as to the relation between chemical composition and psychological effect; and when we have the chemistry of these "chemical senses" elucidated from this point of view, it will be possible to construct compounds which will have particular flavors — that is to say, particular actions on the olfactory nervous apparatus, just as it is already possible to construct hypnotics which have a predictable action upon that part of the nervous apparatus which is concerned with sleep.

So much for our account of the "five senses", though we have found that they are many more than five, and though there are several more to consider. It remains for us briefly to consider the æsthetic and ethical questions which are raised by the comparative study of the various senses so far as we have pursued it. We have already stated certain grounds on which the eye and the ear are to be regarded as superior to the other senses. Let us remind ourselves, further, that taste and smell, like the cutaneous senses, are, above all, concerned with our protection rather than with our instruction; they exist for the preservation of the body rather than the illumination of the mind. The chief functions of the nose and tongue are to cause us to avoid or reject things which they find offensive, and which, in fact, are almost invariably found to have noxious properties associated with those which cause these senses to dislike them But it is the body that they are concerned with, and only with difficulty and rarely can they be made available for higher purposes.

The senses that minister to the body and those that affect the spirit

That is why we instinctively feel entitled to apply to pursuits of certain sensations, including those of the "palate" (which is midway between tongue and nose, and stands for the combination of both), the condemnatory word sensual; while we decline to apply the same word to the lover of music or pictures, except when the music or pictures are, as we say, of a sensual kind. The question which determines our judgment is the extent to which the sense which is being gratified leads to the mind through the body, or stops short at the body, and thus never leads to anything more than sensation The reason why the pleasures of visual and auditory art are regarded as elevating and worthy of admiration and respect is that these senses are the gateways of "Man-*soul*" indeed, and excite emotions, which are often noble or ennobling, in the very citadel of our being.

Looking to the end the test of human tendencies

This is the true and final reply to those who argue that it is just as well to enjoy a good meal as a noble picture or symphony, or even a noble poem. Here, as elsewhere, the everlasting criterion holds — "Look to the end thereof". As Tolstoi showed in his profound and powerful book "What is Art?" we must name and appraise any art, psychologically and morally, in terms not of the mere sensations at the surface of our bodies, but in terms of the emotions it conveys to ourselves The sensory pleasure may be extraordinarily acute in the case of smell, as the result of fine cooking, or even from contact with soft materials. But we place these low in the scale because they lead nowhere; while great art, merely using the senses, can "purge the soul with pity and terror".

MODERN METHODS OF PROSPECTING

HOW HIDDEN ORE & OIL DEPOSITS ARE LOCATED

IN many ways our knowledge regarding the earth's crust is very incomplete and, because of industry's mounting drain on natural resources, it is daily becoming more evident that this is a tremendous handicap, when searching for new deposits to take the place of those being depleted.

Until recently, prospecting for new deposits was usually limited to a study of rock outcrops, shallow test-pits and drill holes. Of these, the first furnish the best key to what lies beneath the surface. Unfortunately, in most mining and oil districts, rock exposures cover less than two per cent of the total surface, and therefore conclusions regarding the hidden ninety-eight per cent of the crust have been rather general. Large areas in the temperate zone are more or less masked by a thin veneer of soil; in the tropics the rock has been rotted so deeply and the vegetation is so dense that a geological report is often impossible; and in Canada and northern United States the recent continental glacier left behind an immense amount of debris which either directly conceals the rock crust, or effectively hides it under thousands of lakes and swamps, occupying hollows in this glacial material.

It is true that in those regions where dependable rock outcrops are plentiful, a geologist can rather accurately foretell the underground structure, but a majority of such areas have already been carefully studied. Thus the really important territory for present and future prospecting is that great virgin reservoir—the hidden portions of the earth's crust. Any economical method which will pierce the covering mantle and reveal the presence or absence of ore deposits and the structure of the underlying bed-rock is of inestimable value.

Perhaps the first device for locating hidden deposits was that used by the water witch, and even today many water wells are drilled on locations determined by the twisting of a forked hazel twig. The next scheme was to tie a gold nugget to the hazel twig and witch for gold; or a vial of crude petroleum and locate an oil field. To the scientifically trained man all of this may seem absurd, crude methods of the distant past, designed to hoodwink ignorant people; and yet it was only half a dozen years ago that some of the shrewdest oil operators in the United States were tricked by a modern forked twig. Upon investigation this "wigglestick" proved to be merely two coiled aluminum springs joined so as to form a fork, at the center of which was a platinum vial containing a secret chemical which, supposedly, had an affinity for oil. Of course, hazel twigs, "doodle bugs" and "wigglesticks" are fakes and it was probably after an experience with them that Mark Twain described a mine as a hole in the ground opened by a liar.

Scientific detection of hidden ore bodies is always based on a difference between the inherent properties of the ore body and those of the enclosing medium. Where such a difference does not exist, the new prospecting instruments furnish no clue; but where there is a change in physical properties—as magnetism, density, electrical conduction, transmission of earthquake shocks and radio waves—then

modern scientific methods enable the geologist to locate hidden deposits. By way of illustration, an analogy may be drawn between hunting submarines under water and locating ore deposits underground. During the Great War the detection of a motionless submerged submarine was a serious and, at first, a difficult matter as there was no sound from the propeller which might be detected through hydrophones. However, experiments soon demonstrated that a submerged steel vessel has magnetic and electrical properties, and that it reflects sound waves. So, by using instruments sensitive enough to register differences between the submerged vessel and the enclosing medium of sea water, the detection of submarines, toward the close of the war, became fairly easy.

Before describing the modern methods of locating valuable hidden deposits, it might be well to emphasize the fact that they are based on definite physical principles determined through careful experiment, and hence have nothing in common with the "wigglestick" and "forked twig." Moreover, it would be unfair to expect all of them to work equally well in such a great variety of complex situations as nature affords. So it is customary to make a preliminary geological survey, so that the geophysical method of testing that is used really suits the existing local conditions.

Magnetic methods

We are all familiar with the compass needle and know that, if free to swing about a vertical axis, it will point toward magnetic north. But we often forget that magnetic north usually does not coincide with true geographic north. At New York City, for instance, a compass will point about ten degrees west of true north, while in Montana the same compass will point twenty degrees east of true north. This is due to the earth behaving as a huge but irregular magnet, the intensity of whose magnetic field varies from place to place both horizontally and vertically. A compass measures horizontal variations, and if a magnetized needle is suspended on a horizontal axis it will dip or point downward into the earth, thus affording a measure of vertical changes of intensity. Determinations of horizontal and vertical variations in the earth's magnetic field have been made for many years at various stations, and maps are available which show points of equal intensity over all the earth's surface.

Another device is the magnetometer, the purpose of which is much the same as that of the torsion balance. The entire earth is, in a sense, an enormous magnet, with lines of force radiating outward from the poles. Most materials of the earth's crust act as screens to prevent passage of the magnetic lines of force. The various strata act as screens. The lines of magnetic force pass easily through the strata with "coarse mesh," but have to "struggle" to get through beds with "fine mesh." Where the stratum is extremely impervious, the lines of force have to "detour." The various types of rock have their peculiar ways of "warping" the lines out of their normal course. It is this crowding and distortion of the lines which the magnetometer measures.

The question now naturally arises, how may these principles of the earth's magnetism be used in locating hidden deposits? A major part of the earth's crust is composed of rocks and minerals which are not affected appreciably by the earth's magnetic field. Fortunately, however, some ores of iron are like steel in that they retain a part of the earth's magnetism and are always magnetic unless heated or jarred. The lodestone of the ancients, or magnetite (Fe_3O_4) as it is called in the iron mines, is a common example. Wherever this mineral is abundant, the earth's magnetic field is disturbed; its presence is indicated by local variations in the horizontal and vertical intensity of magnetism and this can be measured with a sensitive compass, a dip needle or an earth inductor. Knowing from accurate maps what the normal magnetic intensity should be, it is an easy matter to decide whether the local variations are of sufficient magnitude to indicate a deposit worth while. For instance, Figure 1 illustrates a local condition which would signify workable ore, even though the surface were completely hidden

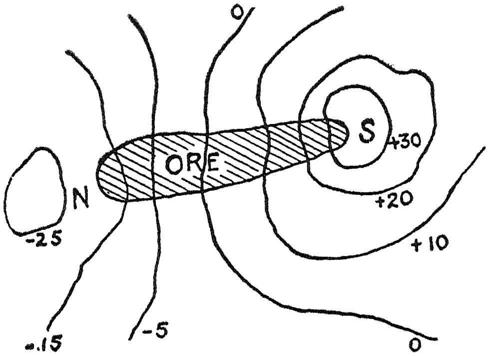


FIG. I. PLAN VIEW SHOWING LINES OF EQUAL MAGNETIC ATTRACTION

Because of its strong magnetic character and its wide distribution in both igneous and sedimentary rocks, magnetite, even if present in only small amounts, often furnishes an excellent key to underground structure. In recent years field instruments have been developed which are fifteen times more sensitive than formerly. It is now possible to measure changes in the earth's magnetic field of the order of five parts in ten thousand, and a rock containing only one-tenth per cent of magnetite will produce an easily observable effect. Thus it is possible to trace buried faults or breaks in the rocks; to indicate concealed dikes and intrusions of basic material; and, if the magnetite is evenly distributed, to locate underground folds.

Seismic or earthquake methods

When an earthquake occurs or a bomb is exploded, the sound travels through the air and the shock moves through the ground. Sound travels about 1,100 feet a second and shock is radiated through the rocks near the earth's surface at about 6,000 feet a second. In general the velocity of a shock wave depends on the density and elasticity of the rock through which it is passing, and the speed increases roughly with depth.

If an artificial earthquake is made by exploding 150 pounds of dynamite buried in the ground, the shock can be detected six miles away with an earthquake recorder or seismograph. This sensitive instrument magnifies the movement due to the shock about ten thousand times, and, therefore, when used in the field, it must be protected from jarring, temperature changes, and even from gentle breezes. The seismograph preserves the wave motion of the shock on a roll of paper and records the time of the explosion by wireless, as well as the time of the shock's arrival. Knowing the distance traversed and the time elapsed, the velocity or speed of the shock is obvious.

To appreciate the significance of this seismic method of prospecting it is necessary to go back to the discovery in 1901 of the great Spindletop Oil Field (see lower picture on this page). Here for the first time was demonstrated the economic importance of the salt dome as a locus of oil fields. Figure 2 is a geologic cross-section

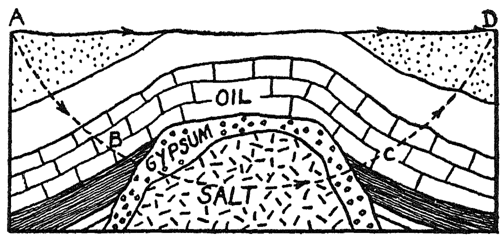


FIG. 2. COMPOSITE SECTION OF THE SPINDLETOP OIL FIELD

of this famous Gulf Coast field and Figure 3 shows its richness by the close spacing of the derricks. Immediately after this discovery, a drilling campaign was started and within the following two or three years some forty-five salt domes were drilled; in fact this comprised about all the domes that could be found by the usual geologic methods. During the succeeding twenty years a great many additional wells were drilled along the Gulf Coast and literally millions of dollars were spent blindly searching for new salt domes. Because of the absence of rock outcrops, the total result of this drilling orgy was just five additional domes.

A number of years ago, artificial earthquakes were tried in the area along the Gulf Coast for the first time, and as a direct result some thirty new salt domes have recently been discovered. During the fall of 1928 more than twenty-five complete seismic crews were working in this territory and at times one was faintly reminded of

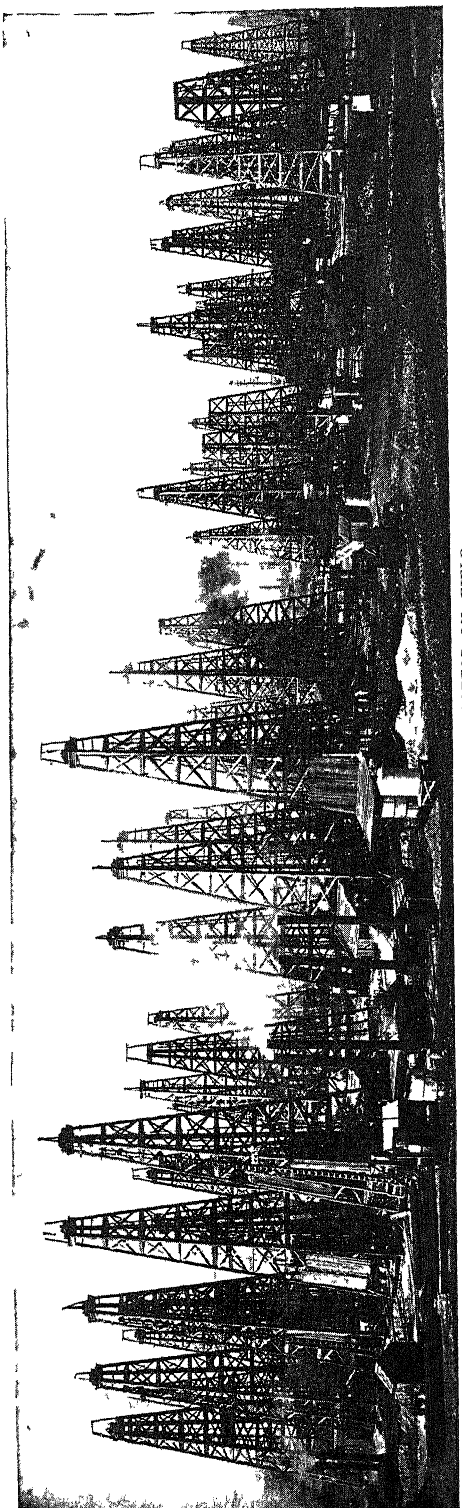


FIG. 3. WELLS IN THE SPINDLETOP OIL FIELD

This unnecessary closeness of boring would have been avoided by present methods of prospecting

the Great War. The price of dynamite, compensation for the privilege of wrecking the landscape, and the salary of expert instrument men bring the cost of operating a standard seismic crew to between twenty and forty thousand dollars a month. Since each crew can explore from a few thousand to two hundred thousand acres a month, depending on the type of territory covered and the detail desired, the Gulf Coast is being rapidly explored.

Coming back now to the method itself, the basic principle upon which the discovery of hidden salt domes depends, is really very simple. The shock wave arriving first has come by the *quickest*, not the shortest route. Because of the high elasticity and low density of the salt, shock waves passing through it have a velocity of around 16,000 feet a second, which is about three times faster than in any other formation of the Gulf Coast area Thus, referring to Figure 2, the quickest route of a shock wave is along the path ABCD, not along the short cut AD; and so an unusually quick arrival of a shock would indicate the presence of a salt dome between the instrument and the explosion.

Gravitational methods

When desirable, the actual value of gravitation may be determined by using a sensitive reversible pendulum, and its variation from place to place shown. In this way the presence of large dense ore bodies and buried mountain ranges may be demonstrated by an increased gravitative pull. In general, though, the method is not sufficiently accurate, being sensitive to only three parts in a million.

In exploring a region it is not really necessary to know the actual value of the gravitative force; a comprehension of how this attraction varies from place to place is sufficient. Therefore any instrument that measures very small changes in gravity is extremely valuable in locating hidden deposits and in deciphering the underground structure of the earth's crust. Such an instrument is the torsion balance, and with it changes in gravity of the order of one part in a million million may be detected.

Today over one hundred of these costly instruments are being used in the United States searching for new ore deposits and oil fields.

The underlying principle of the torsion balance is relatively simple, and in Figure 4 is shown the original idea developed by Baron Eotvos. Two small masses of gold are supported at the ends of a light horizontal bar. One of these masses (B) is placed at one end of the bar and the other mass (C) is hung some distance (60 centimeters) below the opposite end. The bar is supported at its center by a fine wire (A).

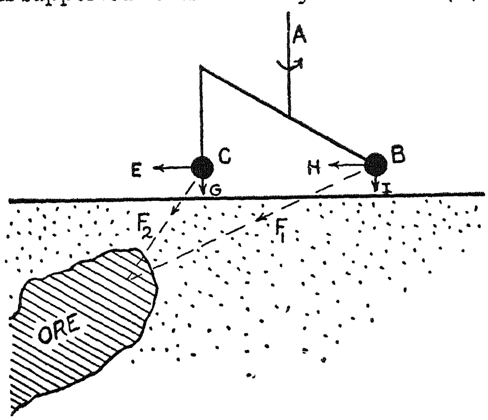


FIG. 4. DIAGRAM OF TORSION BALANCE BEING AFFECTED BY A HIDDEN ORE BODY

Suppose this instrument were set up near a hidden dense ore body. Then a force (F_1) would act on the mass B and a slightly greater force (F_2) would act on the nearer mass C. Since the vertical components of this force (G and I) would be the same, and since the horizontal component E would be greater than H, there would be a twist on the bar, causing it to turn until the torsion in the suspending wire (A) exactly balanced it. The amount of twist given to the wire is measured photographically, and usually six readings, with the bar in different directions, are required at each station. In field practice the instrument is enclosed, because of its sensitivity to drafts and temperature changes. To speed up observations two balances (Figure 5) are often combined in one instrument.

The torsion balance method can handle certain types of natural conditions brilliantly; it does fairly good work in others; and can do nothing at all in many cases. Where topography is uneven and rough, so many large corrections must be applied to the original data that the results are often untrustworthy. As a practical illustration of its value in locating favorable underground structure, three torsion balance reconnaissance surveys were made in southern Oklahoma. The data indicated

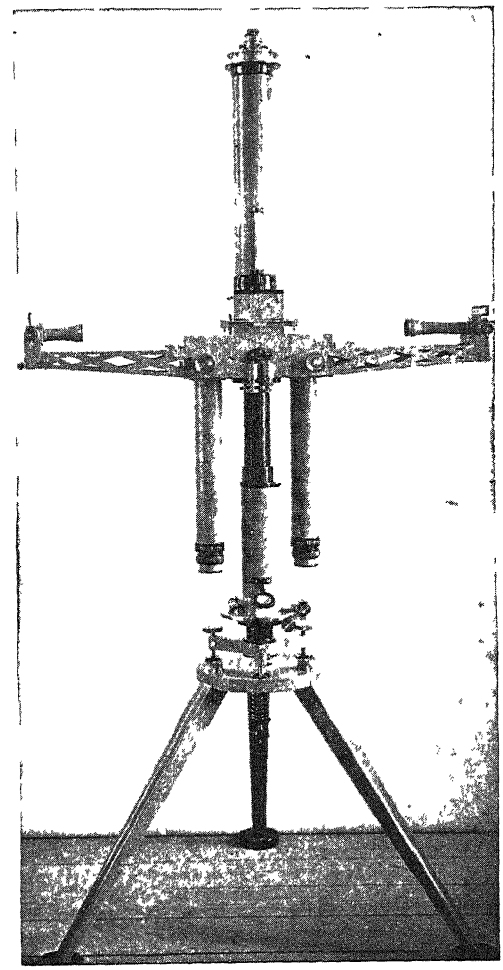


FIG. 5 THE EOTVOS TORSION BALANCE

seven first-class structure possibilities, and if two wells had been drilled on each possibility there would have resulted two first class oil fields, one second class field, and one or two fourth class fields.

Summarizing, the torsion balance method is excellent for locating ore deposits when hidden under flat topography; its success in discovering and defining salt domes and

other structures is of about the same degree as that of geology in finding oil—it merely reduces the usual risk.

Electrical methods

Rain water seeping through the soil usually oxidizes and changes the top part of an ore body more than the bottom. As a result, currents of electricity flow continually from the bottom to the top, completing the circuit through the better conducting ore body. In such localities the existence of these currents may be easily detected and the ore body discovered The method is delightfully simple and usually works well if the ore body is near the surface.

In the majority of electrical prospecting, however, a current of known potential is made to flow through the ground between two electrodes. The discovery of any hidden ore body results from the fact that it conducts this imposed current differently than does the surrounding rock. Quite a variety of methods is used and each has its own peculiar advantages. The underlying principle is the same in each, and this is illustrated in Figure 6.

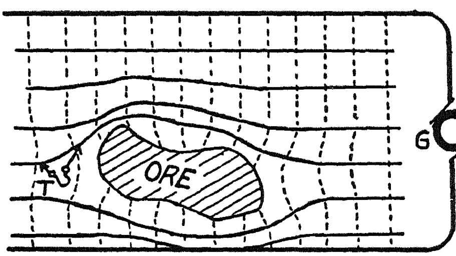


FIG. 6

Diagram showing the effect of an ore body on lines of current (dotted lines) which normally should flow perpendicular to the copper conductors G is the alternating current generator. T is the earphone used for getting silence-points on the equipotential lines (solid lines).

Here two bare copper conductors about 3,000 feet long are laid on the ground parallel to each other and 1,000 feet or so apart. These conductors are grounded to the earth every one hundred feet through metal pegs and are connected to a portable alternating current generator. Under normal conditions the lines of current will flow perpendicularly to the conductors (shown by dashed lines) and lines of equal force or potential will be parallel to the conductors (shown by heavy lines). With such a simple grid arrangement any disturbance due to a differently conducting medium, such as an ore body, will be immediately apparent. To show this, the area between the conductors is searched with two movable electrode pegs connected to an amplifier and ear-phones If one electrode is temporarily fixed and the other moved about until the noise in the ear-phones becomes a minimum, then both electrodes are on a line of equal force. The deviation of these equipotential lines from the normal pattern gives the position of the ore body.

Many brilliant discoveries have been made with electrical methods, especially in the search for metallic ore bodies and for water-bearing strata. This method depends upon the electrical conductivity of the body sought, and also upon its shallowness. Where rock outcrops are scarce and lakes are present, electrical methods have been successful, especially since they may be used to good advantage when lakes are frozen.

Wireless or radio methods

Doubtless every one is familiar with the use of radio waves in aiding ships to steer their way into port or in locating their position at sea. A ship can pick up signals of maximum intensity from a port only when its radio coil is straight with the sending station. Or when a ship at sea sends signals, a coil on the coast receives them at maximum intensity only if its plane points straight to the ship, the signals not being received when its plane is at right angles to that direction. Using this simple principle, radio waves have been employed to discover hidden ore bodies.

Since ore deposits cannot send radio signals it is necessary to excite or stimulate them with electro-magnetic waves from a transformer with an aerial. This causes the ore body to radiate secondary waves and these latter may be detected by a receiving loop. It is essential that the coils be tuned so that both the primary and secondary radio waves have the same phase, in which case the detection coil will give a minimum noise when its plane is pointing toward the ore body.

Short waves (40 meters) such as used in amateur sending will not traverse many feet of rock. The ordinary broadcast waves (400 meters) are much better, and longer waves (10,000 meters) can be detected to a depth of 500 feet or more. Since fifty feet is the greatest depth to which radio waves will penetrate the ocean, it is evident that the moisture content of the surface rocks will directly affect the success of this method.

Summary

From the foregoing brief discussion of the new methods of prospecting it appears that all of these schemes have merit.

Wireless or radio methods continue to challenge experimenters, but the practical stage with authenticated discoveries has not yet been reached. Although the refraction seismic method is occasionally used, it has been largely supplanted by the reflection seismograph. Similarly, the torsion balance gravitational method has been largely replaced by the gravity meter, which measures gravity directly, and which is in principle simply a glorified spring balance.

The relative importance of the leading methods at the present time (1943) is, (1) reflection seismograph, (2) gravity meter, (3) magnetic methods, and (4) electrical methods. The first two are used chiefly in oil exploration. The latter two are used to some extent in oil exploration, but have their greatest utility in the search for metallic ore bodies.

Under certain conditions some are better than others and, needless to say, conflicting results are frequently obtained with different methods. It is somewhat analogous to the conflict in the description of an elephant by three blind men—one of whom felt the tail, the second a tusk and the third the trunk. This conflict of performance is often due to poor interpretation of data or to local effects which are not correctly considered.

Finally, these methods are not a cure-all for prospecting and at present they do not replace a geologist in those areas where outcrops are abundant.

Courtesy Standard Oil Co. (N. J.)

FIG. 7. A MAN-MADE EARTHQUAKE IN ACTION

The sensitive instruments of the seismograph crew record the resulting sound waves. From the information so obtained, the geo-physicist can determine where oil is likely to be found.

STREAMLINING RECORD COLLECTIONS

Columbia Records

A graphic illustration of the space savings made possible by LP (long-playing) records. This man is holding in vinylite LP records the equivalent of the pile of "78" shellac records shown at the left

MACHINES THAT TALK

How the Electronic Amplifying System Brought New Fidelity to Phonographic Reproduction

SPEECH REPRODUCED BY STEEL WIRE

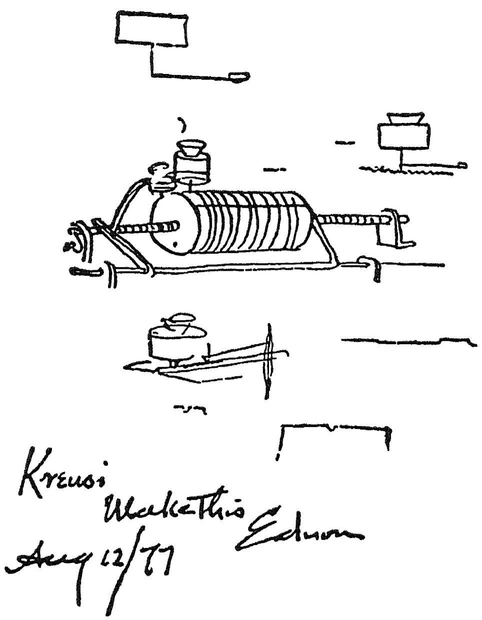
SOME years ago an American lad was anxious to become an expert telegraph operator. He was engaged at small pay in a telegraph office at Indianapolis in the daytime, but he was so keen to succeed that his day's work did not suffice. It was at night, when the line was being used for newspaper work, that speed in receiving messages was most necessary; and the lad figured that if he could get some of this night-work to do the practice would make him an expert, and enable him soon to earn bigger pay. The regular night operator was a man who often took more to drink than was good for him, and he was very glad when the boy offered to help him. So, while he was sleeping off the effects of his potations, the lad did his work for him. The ambitious youngster, however, was not by himself equal to the task, but he inspired another boy in the office with his desire to become an expert operator, and by working together they soon managed to get along fairly well. They each sat down for ten minutes at the instrument, and transcribed as much of the report as they could, and carried the rest in their memory. While one was writing out, the other was taking down.

This plan worked sufficiently well until a new man was put on at the Cincinnati end of the line. Now he was one of the quickest despatchers in this country, and the two lads found that it was hopeless to attempt to keep up with him. Yet the boy who had first resolved to become an expert operator did not mean to lose his chance of success without a struggle. His name was Thomas Alva Edison and the difficulty into which he had got himself spurred him on to devise the first of his inventions. Necessity was certainly the mother of it.

He obtained two old Morse registers, and made out of them a kind of tape machine. A strip of paper was run through the first receiving instrument, and as fast as the dots and dashes came from the Cincinnati despatcher they were printed in indentations on the paper. The paper was then run through the second instrument at the slow speed at which the two lads were able to work. So the messages would come in on one instrument at the rate of forty words a minute, and the two boys would grind them out of the other register at the easy speed of twenty-five. Mighty proud were the youngsters of their achievement. Their copy became so clean and beautiful that they hung it up on exhibition. The manager of the office used to come and gaze at it silently with a puzzled expression. His two infant prodigies, it seemed, were more than a match for the swiftest despatcher in the United States. He could not understand it; neither could any of the other operators. For the lads used to drag off their automatic recorder and hide it when their work was done.

But one night they could not keep up with their task. A presidential election was in progress, and copy kept pouring in at the top rate of speed, and the young operators fell two hours behind with their work of transcription. The newspapers sent in frantic complaints, an investigation was made, and Edison's little secret was discovered. He was not allowed to use his automatic recorder any more.

But he kept his machine for converting telegraph clicks into printed marks and changing these marks again into sounds. He went on improving the instrument, and by 1877 it was fairly perfect. It had an electromagnet connected with an embossing point, and when connected with a telegraph circuit the point would vibrate and indent the dots and dashes on a revolving disc of paper. The instrument would repeat the messages at any rate of speed desired. One day, as Edison was experimenting with the instrument and trying it at various rates of speed he noticed



FACSIMILE OF EDISON'S SKETCH FOR THE MODEL OF THE FIRST PHONOGRAPH

that one of the indented discs of paper, if revolved at a high rate, would emit a musical note. At that time he was also experimenting on the telephone and working out improvements on Alexander Graham Bell's ideas — his mind was filled with theories of sound vibrations, and their transmission by drum-like membranes. On hearing the musical note given out by the revolving disc an idea struck him that there was a possibility of recording and reproducing the vibrations of air caused by the human voice and other sounds. Hastily rigging up a crudely improvised instrument, he pulled through it a strip of paraffine coated paper and shouted against it, "Whoo-oo-oo." He then pulled the paper through again, and listened breathlessly A faint, though distinct, sound was heard, but that was sufficient for Edison, who made this entry on his laboratory note book on that day, July 18, 1877:

"Just tried experiment with diaphragm having an embossing point and held against paraffine paper moving rapidly. The speaking vibrations are indented nicely, and there's no doubt that I shall be able to store up and reproduce automatically at any future time the human voice perfectly."

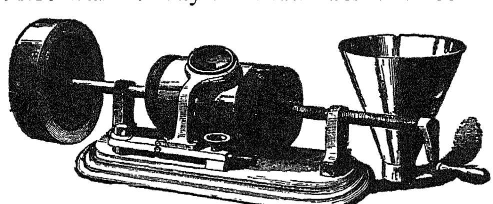
One of his workmen, Charles Batchelor, was very skeptical and offered to bet him a box of cigars that he couldn't make the thing go Edison took the bet and kept on revolving the thing in his mind as to the best method of putting his ideas to a practical test.

On August 12, 1877, he made a rough drawing and wrote on it, "Kreusi, make this." He handed this sketch to one of his workmen, the late John Kreusi, saying, "Here's an eighteen dollar job for you." Kreusi, who was accustomed to this sort of procedure, looked at the drawing and said, "What are you going to do with this?" To which Edison replied that it was intended to be a machine that would record and reproduce speech. Kreusi said, "You're crazy this time," but he set to work and made the model from the drawing and in a few days brought it to Edison and stood by with a grin on his face. With much deliberation Edison fixed a sheet of tinfoil around the cylinder, adjusted the metal point and through the funnel shouted the words:

" Mary had a little lamb,
Its fleece was white as snow," etc.

He then adjusted the reproducing diaphragm, and on turning the cylinder again the words came back — a little squeaky but quite plain. Edison was astounded, for he had not expected such perfect results upon the first trial for the first model. Kreusi turned pale and said, "Mein Gott in Himmel!" Thus the phonograph came into existence — and Batchelor lost his bet.

Edison was not the first to attempt to record the vibrations of sound. For instance, Leon Scott in 1855 had invented the "phonautograph", an instrument which consisted of a speaking-horn, shaped like a small barrel, and made of plaster. The upper end was left open to receive sounds, and the lower end was fitted with a short brass tube about four inches in diameter. Over the end of the tube a flexible membrane was fixed, like the head of a drum. On the outside of the membrane was fastened a hog's bristle, which acted as a stylus or pen. In front and within reach of the bristle, was a cylinder covered with smoked paper. The cylinder was turned by a handle, and as it revolved it also moved forward in answer to a screw-thread cut on its axle. The bristle traced a wavy line on the sooty paper, that is, "wrote the sound", but there was no way in which the lines could



From *Scribner's Monthly*, April, 1878
"EDISON'S SPEAKING PHONOGRAPH"

be reproduced again *in* sound. But Edison's phonograph was not merely a sound-writer; it was a sound-reproducer. For when the little steel pen began to travel again over the indentations it had made in the tinfoil, it caused the membrane to vibrate in response to its movements, just as the membrane of a telephone receiver vibrates in answer to the electric current set up by human speech at the other end of the wire. As the membrane vibrated it made sound-waves. So the machine talked. In other words, the membrane of a phonograph does the work first of the human ear and then of the human voice. First, it vibrated to the air-waves of sound, and transmitted them, by means of its stylus, to the tinfoil. Then it vibrated in obedience to the up and down motion of the stylus along the indented lines of the tinfoil and made all the articulate sounds of speech and song.

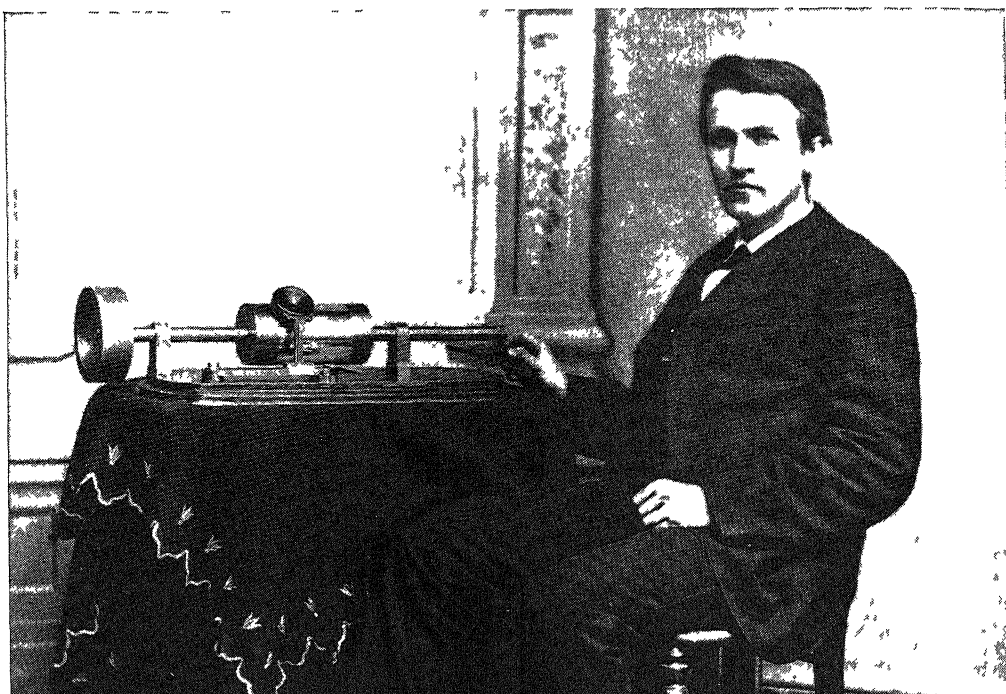
Marvelous as were the first talking-machines that Edison devised, they were little more than scientific curiosities. The reproduced sounds were distressingly "tinny" and unmusical. It was difficult to remove the tinfoil from the cylinder or to replace it without distorting the material and injuring the indentations. So it was necessary to have a separate cylinder and screw and crank for every new record Moreover, the motion given to the cylinder by turning a handle was not regular. Now, the pace at which the diaphragm is vibrated has an important effect on the quality of the sound. Too high a speed makes the note sharp, too slow a speed makes it flat; and both make it very unmusical, and false and distorted.

After a few months of work and experiment with the phonograph, Edison laid it aside for the time being, as he became intensely busy with his monumental work on the incandescent electric lamp and system of electric light, heat and power. He saw, however, the possibilities of the phonograph and contributed an article to the *North American Review* of June, 1878, in which he prophesied its future with startling accuracy. Alexander Graham Bell, too, saw that possibilities lay in the talking toy, and, assisted by his brother, Chichester, and by Charles S. Tainter, he produced a machine called the graphophone, in which clockwork was used instead of hand motion, and the record and reproduction of sounds were much improved. Instead of the tinfoil, there was employed a thin mixture of wax on light paper cylinders, and the new machine was comparatively more convenient and effective than the rather crude original phonograph.

But as soon as Edison had some time to spare he also began to improve upon his original ideas, and produced a new machine in which a special wax cylinder was used. The record was cut by means of a tiny agate or sapphire point, which made minute depressions in the wax. The reproducing point was also of sapphire. It passed over the indentations and communicated its movements to the membrane or diaphragm by means of a delicate combination of weights and levers.

In Edison's phonograph and all its varieties, the record in the wax was formed of a series of little hills and dales, running round and round the cylinder or disc. Thus the sound-waves were represented by actual waves in the wax, each wave sloping upward and downward like the rippled surface of the sea. When in 1886 Bell and his partners patented their graphophone, they kept to what is now known as the "hill and dale" groove. But another inventor, Emile Berliner, who had been working on a new device in connection with the telephone, became interested also in experimenting on talking-machines and departed from the "hill and dale" method by causing the engraving tool to move from side to side in the groove. This was particularly adaptable to a disc type of record and is known as the "lateral cut." The type of machine invented by Berliner in 1887 was called the gramophone, which later was merged into the Victor.

Externally the chief difference between the gramophone and the phonograph was that the gramophone records consisted of thin, flat discs. A single movement of a turntable spun the disc around and worked the instrument. In the cylinder type of the phonograph, on the other hand, there were two movements. First the cylinder had to be turned round; then, while it was turning, a secondary motion had to be imparted to the pen and the diaphragm that travel with a sideways movement over the revolving cylinder. This secondary motion, by means of a separate feed-screw, was not needed in the gramophone.



Brown Brothers

Thomas A. Edison and his first talking machine. It utilized a rotating cylinder instead of a disc.

Another difference between the gramophone and the older instruments lay in the manner in which waves of sound were translated into waves of wax. Berliner thought that both Edison and Bell were at fault in adopting the "hill and dale" method of recording sound. He claimed that the needle might jump from the top of one hill to another, and miss the dales. Berliner claimed that he avoided this by inventing something quite different. In the Berliner cut, the depth of the grooves in the record was always the same.

RCA Victor

This diagram of a 45-rpm (revolutions per minute) phonograph shows how sound is reproduced from a phonograph record. The undulating grooves cut into the record are an accurate representation of the original sound. These undulations are produced by the vibration of the recording stylus or "needle" in response to the undulations of the original sound waves picked up by the recording microphone. The reproducing stylus in the tone arm of the phonograph follows the undulations in the walls of a given groove. The resulting vibration activates the crystal pickup immediately adjoining the stylus, the pickup generates electrical impulses that correspond to the movements of the stylus. These electrical impulses are carried by wire to the amplifier, which increases their strength and feeds them to the loudspeaker. The loudspeaker then reproduces the original sound, music or spoken words.

In the course of the years that followed, various improvements were made in both recording and reproducing. By the early years of the twentieth century a fairly standard sort of sound box had been developed for reproduction purposes. The discs were made to revolve by a clockwork machine; a mica diaphragm transmitted the sound-waves to the ears of the listener through a big horn, which was fixed by a bracket to the sound box. Later the horn was inverted and placed inside the cabinet.

The limitations of the old-fashioned kind of phonograph

Phonographs still had very definite limitations, which could be traced to the lack of power of the human voice or of musical instruments. The ringing tones of a voice may be very loud; but the power output of its vibrations cannot begin to compare with the power that is required, say, to light a hundred-watt bulb. The changing vibrations that caused the engraving tool of the old phonograph recorder to move from one side of the groove to the other were so feeble that many tone values were lost. That is why it was necessary, when making recordings, to husband the available power of the vibrations. In old-time recording studios artists kept close to the recording horns, and they spoke or sang as loudly as possible. Since only a few musicians could get near the horns at any one time, only the smallest orchestras were used.

The electrical method of recording has been in use for years

All this changed once and for all when the electrical method of recording was adopted. This method, which has been in use for years, is based on much the same system as the radio. First, sound-waves are converted into electric current by means of a microphone. The variations of pressure caused by the varying intensity of the sound-waves are matched by changes in the strength of the electric currents.

The changing currents are enormously magnified by means of an electronic amplifying system; then they are used to operate the recorder that carries the cutting tool, or stylus. When the record is to be played, the vibrations picked up by the phonograph needles are converted into electric currents. These currents are passed through the amplifying system of the electrical phonograph or radio-phonograph combination, and are then transformed into sound-waves again in the loudspeaker.

As an electronic amplifier can magnify an electric current to almost any desired extent, it is possible to start with exceedingly small currents. Therefore, it is no longer necessary for artists to crowd around the recorder as they did formerly. Moreover, the sound reflections from the walls of the studio can be used to improve the quality of the sound, just as they do in a well-designed concert hall.

The different kinds of phonographs utilizing electronic equipment

The electronic equipment that the phonograph utilizes is sometimes contained in a radio-phonograph or radio-phonograph-television combination; sometimes the phonograph is attached to a radio and utilizes the radio's electronic circuit; sometimes the phonograph contains its own electronic circuit and is an entirely independent unit.

In the late 1940's there was an important new development in the field of recording. Until that time the ordinary record revolved on the turntable of the phonograph at the rate of about seventy-eight times a minute, and each side of the record played for only a few minutes. Since the constant changing of records plagued music lovers, automatic record-changers were devised; these could play a number of records in succession. In many models the records were placed over the turntable and were dropped automatically upon it, one after the other.

The introduction of long-playing records for home use

For some years radio stations had used larger discs, or platters, which turned only 33⅓ times a minute and which played far longer than the ordinary kind of records. In 1948 and 1949 two new types of long-playing records for the home were introduced and became very popular.

In one of these types the record revolves 33⅓ times a minute; each side of a 12-inch record can play as long as 20 minutes. The other kind of long-playing record revolves 45 times a minute. It is much smaller than the conventional "78" disc, but it plays just as long. Both "33⅓" and "45" records save storage space. For example, an entire symphony or concerto can generally be recorded on a single "33⅓" disc; three or four "78" discs would be required for the same recording.

Vinylite is a favorite material for modern records

Formerly all records were made of a mixture consisting mainly of shellac, with coloring matter and an abrasive material. Nowadays all "33⅓" and "45" records are made of vinylite, a lightweight plastic material. Vinylite records are not fragile like those made of shellac; furthermore, there is less surface noise than in the case of shellac records because of the absence of abrasive material. Many "78" records are now being made of vinylite.

Magnetic recording, discovered by Valdemar Poulsen

An entirely different principle of recording is used in magnetic recording, discovered in 1900 by Valdemar Poulsen in Denmark. In this method, sound vibrations are changed into electric impulses, much as they are in radio. These changing electrical impulses affect the strength of an electric magnet. Wire or tape is drawn lengthwise past this magnet and becomes magnetized; to all intents and purposes it has become a string of small bar magnets.

Since the strength of the big magnet changes constantly, the amount of magnetism in the wire or tape that travels past it will vary accordingly. Hence the wire will carry, strung along its length, a magnetic history of the changes that have taken place in the strength of the magnet. Since the electric currents that continuously modify the magnet's strength represent converted sound-waves, the magnetized wire or tape represents a record of these sound-waves. Thus anything producing sound—an orchestra, a violin, the human voice—can be recorded on the magnetic recorder.

To play back the recording, the magnetized wire or tape is moved past a coil, consisting of many turns of fine wire. As the wire or tape passes by the coil, a small electric current is formed. This current flows into a loudspeaker, where it is converted into sound. The volume of the sound will depend upon the strength of the tiny magnets passing by the coil. A strong magnet will produce a loud sound; a weak magnet will produce a soft sound. The pitch of the sound will depend on how quickly the poles of the magnet pass by the coil. If the poles change rapidly from north to south, the sound will be high in pitch; if the poles change slowly, the sound will be low.

Magnetic recordings can be easily erased from the wire or tape

The wire or tape, wound on a spool, is easily stored away. It never wears out; the sound pattern remains fresh and clear. However, it is possible to erase the record from the wire or tape whenever that is desired, so that a new recording may be made. In this case, the previous magnetization of the tape is overcome by a direct current passed through the coil or by a high-frequency circuit. The same set of poles and coil can be used for recording, reproducing and erasing.

Magnetic recordings are used in a great many different ways

Magnetic recording is used in making transcriptions of radio programs, public speeches, interviews and the like; it is also employed in business dictation. Home magnetic-recording sets are becoming increasingly popular. With a machine of this kind an amateur pianist or violinist can make fine and inexpensive recordings of his playing at any time. If he makes these recordings at definite intervals, he will have an accurate means of determining the progress that he has made. With a magnetic recorder, too, a music lover can make recordings of good music as it comes over the radio, and can thus acquire an extensive record library for a modest outlay.

The French physician Laënnec, inventor of the stethoscope, using the instrument in auscultation. This drawing has been adapted from a painting by Chartran.

Science and Progress (1815-95) VII

by JUSTUS SCHIFFERES

NEW DIRECTIONS IN MEDICAL RESEARCH

AT the beginning of the nineteenth century, medicine had come a long way from the unscientific mumbo jumbo that had disgusted the sixteenth-century anatomist Vesalius (page 794). Yet much remained to be done. The basic causes of disease were still unknown. Medical men were ignorant of just what happened in vital processes like respiration and digestion; they knew little about the true functioning of the liver; the pancreas was a fascinating mystery to them. When in doubt, they had recourse to bleeding (the drawing of blood by surgical instruments) and leeching (the application of the blood-sucking worms known as leeches). Safe anesthesia and antiseptics were unknown. Surgery was still a pretty crude affair. Surgeons were often considered to be no more proficient than the barber-surgeons of former times; their workshops — the hospitals — were feared as death houses.

In the nineteenth century remarkable progress was made in almost every field of medicine. Improved methods of diagnosis were developed. New light was thrown on the functioning of the body organs. The germ theory of disease revolutionized the treatment of many human ailments and gave promise of controlling epidemics of communicable diseases. The introduction of anesthesia and the use of antiseptics made surgery safer, and as a result its scope was greatly widened.

The groundwork for these spectacular advances was laid in the first five or six decades of the century. For one thing, this period saw the development of an instrument — the stethoscope — that has since become indispensable in diagnosis. Its inventor, René-Théophile-Hyacinthe Laënnec (1781–1826), was a native of the French province of Brittany, a regimental surgeon in the French Revolution, a physician in two famous hospitals in Paris and a professor of medicine at the College of France.

Laënnec has told us the story of his invention of the stethoscope. "In 1816," he wrote, "I was consulted by a young woman presenting general symptoms of disease of the heart. Owing to her stoutness, little information could be gathered by application of the hand and percussion [tapping the chest with flexed fingers]. The patient's age and sex did not permit me to resort to direct application of the ear to the chest.

"I recalled a well-known acoustic phenomenon; namely, if you place your ear against one end of a wooden beam, the scratch of a pin at the other end can be distinctly heard. It occurred to me that this physical property might serve a useful purpose in the case with which I was then dealing.

"Taking a sheet of paper, I rolled it into a very tight roll, one end of which I placed over the chest in front of the heart. To the other end I put my ear. I was both surprised and gratified at being able to hear the beating of the heart with much greater clearness and distinctness than I had ever done before by direct application of my ear."

On the basis of this principle, Laënnec proceeded to build his stethoscope (from two Greek words meaning "chest-observer"). In its original form, it was a short wooden tube, up to twelve inches in

length, and widening somewhat toward each end. (The modern version has two ear tubes with flexible attachments.) In 1819 Laennec published a treatise in which he described the use of the stethoscope.

Through the use of Laennec's invention, physicians could now make more accurate diagnoses of diseases of the heart and lungs; they could follow fairly well the spread of these diseases. They could also detect the presence of the fetus in a pregnant woman, since the heart of the fetus beats almost twice as rapidly as that of an adult woman.

There were a number of outstanding developments in physiology in this period. Our scene now shifts to an American frontier army post, where a United States Army surgeon, William Beaumont (1785–1853), has just taken charge of a serious gun-shot case. To quote the good doctor: "Alexis St. Martin [the victim] was a Canadian of French descent, about eighteen years of age, of good constitution, robust and healthy. He had been engaged in the service of the American Fur Company . . . and was accidentally wounded by the discharge of a musket on the sixth of June 1822 . . .

"I saw him in twenty-five or thirty minutes after the accident occurred; and on examination found . . . a protrusion . . . which proved to be a portion of the stomach, lacerated through all its coats and pouring out the food he had taken for his breakfast through an opening large enough to admit the forefinger."

By skillful surgery and constant attention, Beaumont effected a cure. When the wound healed, the stomach remained exposed to the outer air through an aperture about two and a half inches in circumference. It dawned upon Beaumont that he now had a unique opportunity to study the functioning of the stomach, since food could be readily introduced into St. Martin's stomach through the aperture and could be just as readily withdrawn. He therefore proposed to the young French Canadian that he should serve as a living laboratory; in return he agreed to provide the young man with food (and drink) and lodging. St. Martin agreed, and in 1825 Beaumont began the experiments that were to win him lasting fame in the annals of physiology.

He has thus described one of these experiments. "August 1, 1825. At twelve noon I introduced through the opening into the stomach articles of diet, suspended by a silk string and fastened at proper distances, so as to pass in without pain. [These "articles of diet" included highly seasoned beef à la mode, fat pork, lean beef, salted beef, a piece of stale bread and a bunch of raw, sliced cabbage] . . . At 1:00 P M withdrew and examined them. Found the cabbage and bread about half digested; the pieces of meat unchanged Returned them into the stomach. At 2·00 P M. withdrew them again. Found the cabbage, bread, pork and boiled beef all clearly digested and gone from the string; the other pieces of meat but very little affected. Returned them into the stomach again . . . At 3:00 P M. examined again. Found the à la mode beef partly digested; the raw beef was slightly macerated on the surface. Returned them again." There was little change the next time Beaumont withdrew the string. But St. Martin decided that his patron had done enough experimenting for that day; and so the doctor set to work analyzing his notes.

A classic of medical literature

St. Martin proved to be an exasperating sort of laboratory. He was constantly running away and had to be brought back at great trouble and expense. Furthermore, Beaumont found it hard to carry on his experiments, since War Department orders kept him moving frequently from one post to another. However, he persevered and at last, in 1833, presented his findings in a little book — OBSERVATIONS ON THE GASTRIC JUICE AND THE PHYSIOLOGY OF DIGESTION — published at his own expense. It was perhaps the most important single work ever written on the digestive process. It established once and for all the essential chemical nature of this process; it provided basic information

John Wyeth & Brother, Inc

William Beaumont withdrawing gastric juice from the stomach of Alexis St. Martin. From a painting by Cornwell.

about the secretions of the stomach and its functioning. All modern studies of nutrition, all modern diet tables are based upon this remarkable little book. The author's experiments, performed under backwoods conditions, represented something more than a landmark in the history of physiology. They proved that the progress of science does not necessarily depend on the amassing of great funds for research and on the construction of big laboratory buildings.

Another great name in the history of physiology is that of Claude Bernard. This distinguished French doctor was born at Saint-Julien in 1813. He studied medicine at Paris, becoming a pupil of the eminent physiologist François Magendie. Bernard completed his medical schooling in 1843; ten years later he became a doctor of science. In the year 1855 he succeeded Magendie as professor of physiology at the College of France. Bernard was an accomplished teacher and lecturer, but his achievements in physiological research were even more outstanding.

He was the first to show how the pancreas functions; in the course of time this discovery pointed the way to the control of diabetes, a disease in which the pancreas fails to function properly. Bernard also made some remarkable discoveries concerning the functioning of the liver. He demonstrated that the liver modifies the glucose (a form of sugar) that reaches it, turning it into a substance called glycogen, which simply means "sugar-maker." This substance is then stored in the liver. When and if the concentration of glucose in the blood falls below a certain level, the liver transforms part of its store of glycogen into glucose and releases it in the blood stream.

Bernard called the conversion of glycogen into sugar an "internal secretion." Today physiologists would no longer so label it, since sugar is not a specific product of the liver. But Bernard's researches pointed the way to the discovery of bona fide internal secretions — those of the pituitary gland, the thyroid gland, the parathyroid glands, the pancreatic islets of Langerhans and the adrenal glands.

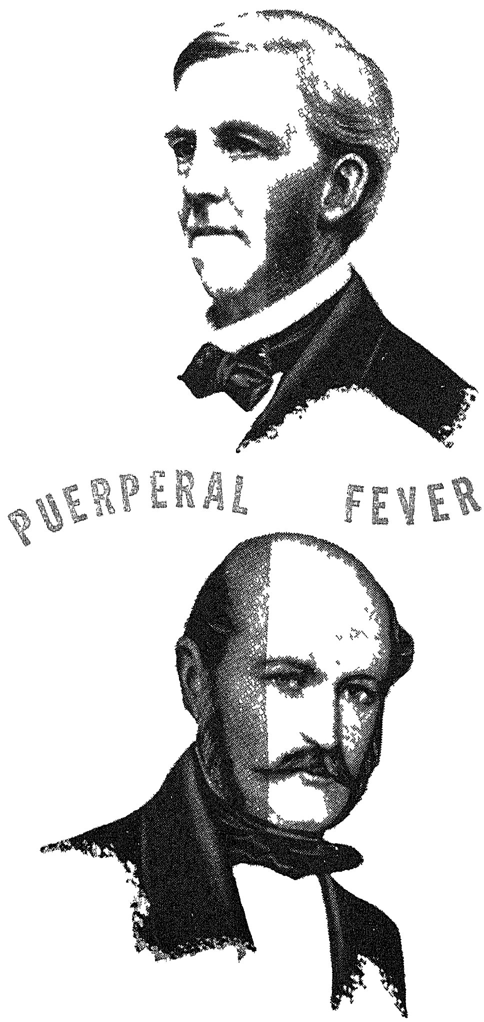
Bernard also did important research on the vasomotor nerves, which control the size of the blood vessels. He demonstrated that vasodilator nerves cause the arteries to dilate, and that vasoconstrictor nerves cause these blood vessels to contract.

This great physiologist won many honors in his lifetime. He became an officer and later a commander of the Legion of Honor; he was appointed to the renowned French Academy and he became the founder and first president of the French Biological Society. Upon his death in Paris, in the year 1878, he was given a truly magnificent public funeral.

The first half of the nineteenth century saw a frontal assault on the disease known as puerperal, or childbed, fever, which attacks women in childbirth. This ailment had long taken a fearful toll. The death rate among women admitted to lying-in hospitals was particularly high. One of the first physicians to call attention to the contagious character of this disease and to the manner in which it was carried from one victim to another was the Yankee medical man, poet and essayist Oliver Wendell Holmes (1809–94).

At a meeting of the Boston Society for Medical Improvement, in 1843, Holmes read a paper, The Contagiousness of Puerperal Fever. He pointed out that the disease "is so far contagious as to be frequently carried from patient to patient by physicians and nurses." And why? Because these doctors and nurses did not clean themselves properly before attending their patients. To Holmes this seemed a particularly blameworthy offense. "The woman about to become a mother, or with her newborn infant upon her bosom, should be the object of trembling care and sympathy . . . God forbid that any member of the profession to which she trusts her life . . . should hazard it negligently, unadvisedly or selfishly!"

OLIVER WENDELL HOLMES



IGNAZ PHILIPP SEMMELWEIS

Holmes' paper aroused the indignation of Dr. Charles Meigs, professor of obstetrics at the University of Pennsylvania Meigs took Holmes' remarks as a direct slur upon the members of the medical profession as a whole. Holmes answered Meigs with another paper called Puerperal Fever as a Private Pestilence; in this, he pointed out that a certain obstetrician called Senderein had scrubbed his hands with chloride of lime before attending his patients, and that as a result the mortality rate among them had dropped amazingly. Not long afterward Holmes became professor of anatomy at the Harvard Medical School. He seems to have become so absorbed in his new duties that he lost interest in the controversy over puerperal fever.

The war against this disease was to be carried on by the man whom Holmes had called Senderein and whose name was really Semmelweis. Ignaz Philipp Semmelweis (1818–65) was a native of Budapest, Hungary, who received his medical training in Vienna. After completing his schooling, he became an assistant in the lying-in hospital in Vienna. It consisted of two different departments, or divisions.

Medical students were taught in the first division; in the second, the women who were to become midwives received their training. In the first division, over a period of six years, there had been 99 deaths per 1,000 births; in the second division only 33. Semmelweis came to the conclusion that puerperal fever was a wound infection transmitted by the hands of the physicians and medical students who examined women during and after childbirth. Sometimes they would turn from one patient to another without troubling to wash their hands. If they did take the trouble, they used only soap and water, and they never quite succeeded in removing all the germ-bearing particles that adhered to their hands.

Semmelweis, who was in charge of the first division, now insisted that all the students should wash their hands in a solution of chloride of lime before examining a patient. The results were truly startling. At the time when Semmelweis issued his order, the death rate from puerperal fever was 120 per 1,000 births; after seven months, the death rate had dropped to 12 per 1,000 births.

Semmelweis' hasty temper had aroused the dislike of his superiors, and he was continually harassed by petty persecution. At last he could endure no more, and he returned to Budapest. In time he became the director of the lying-in hospital in his native city. Here, too, he was the object of much criticism; as a result, his mind was affected. In 1865 he left for Vienna to consult a specialist in mental diseases In the course of a routine examination it was discovered that Semmelweis had contracted the same type of infection that he had spent his life in combating. Soon afterward he died of the infection.

The validity of the position taken by Holmes and Semmelweis was not fully appreciated until the germ theory of disease was later demonstrated. Today puerperal fever is no longer a menace in maternity wards. No longer is infection carried, as Holmes had put it, "from bed to bed as rat-killers carry their poison from one household to another."

As a young man Holmes had studied in Paris under Pierre-Charles-Alexandre Louis (1787–1872), the founder of medical statistics. This is an exceedingly important branch of medicine. It is difficult to prove that one method of treatment or control of disease is better than another; often, only accurate statistics can provide this information. Louis showed the possibilities of the statistical method.

A MEMORABLE VICTORY OVER PAIN

On the 16th of October, 1846 — celebrated in Massachusetts as Ether Day — a great victory was won over one of man's most terrible scourges — pain. That day saw a public demonstration of the first safe anesthetic, ether — or sulfuric ether, to give it its full name — in the Massachusetts General Hospital, in Boston. The discovery of the anesthetic effects of ether was due to three Americans — Morton, Jackson and Long — and it represents one of America's most notable contributions to the progress of science and the welfare of mankind.

Before Ether Day, it is true, anesthetics of sorts had been administered to patients about to undergo an operation. The soporific (sleep-producing) and anesthetic (pain-killing) effects of intoxicating liquids and of the poppy seed — source of morphine, cocaine and laudanum — were well known. The luckless victim of accident, war or disease was sometimes drugged with alcohol or morphine before he took his place on the dirty operating table. But this did not happen as often as one might imagine, for surgeons had discovered that patients drugged with alcohol or morphine were particularly likely to die during or after operations. Often, therefore, the surgeon refused to administer any opiate, and the patient had to bear his pain as best he could. Necessarily cruel, surgery had to be mercifully swift. Naturally, operations lasting hours at a time — like some that take place quite frequently today —

were impossible under such circumstances.

The discovery of a safe anesthetic changed all this almost overnight. Not only did ether make it possible to abolish pain during a surgical operation, but the surgeon no longer had to hurry in order to reduce to the minimum the sufferings of his patient. Many operations now became feasible that would have been quite unthinkable before this time.

Ether was known to chemists years before it was put to practical use to deaden pain. In the 1840's students at the Harvard Medical School occasionally indulged in "ether frolics" — that is, they would inhale the vapor of ether for the mild form of intoxication that it produced. One of the teachers at the Medical School, Dr. Charles Thomas Jackson (1805–80), observed that while under the influence of ether the students seemed to be oblivious to pain. Jackson now began to experiment with sulfuric ether as an anesthetizing agent. One of his students, Dr. William T. G. Morton (1819–68), a dentist who was studying medicine at the Harvard Medical School, became greatly interested in these experiments.

Morton had long sought an effective painkiller that he could use in his dental work. His friend and former partner, Horace Wells, had used nitrous oxide ("laughing gas") to deaden pain in dental treatments, and Morton had been greatly impressed. But unfortunately one of Wells' patients had died from the effects of this anesthetic; shocked, Wells withdrew from practice. Morton realized that he would have to seek a safer anesthetic than nitrous oxide. It now occurred to him that ether might prove to be ideal for this purpose. He experimented with the substance in his own home, first putting his dog to sleep and then testing the effects of the anesthetic on himself. Finally he employed ether on a patient; he removed a tooth without causing any pain.

Morton thought now of the possibility of using ether as an anesthetic in surgical operations. He persuaded Dr. John Collins Warren (1778–1856), senior surgeon of the Massachusetts General Hospital, to let him give ether to a patient who was about to undergo an operation. The date of this demonstration was set for October 16, 1846. A young medical student, Washington Ayer, has left the following eyewitness account of what happened:

"The day arrived; the time appointed was noted on the dial when the patient was led into the operating room. Dr. Warren and a board of the most eminent surgeons in the state were gathered around the sufferer . . . It had been announced that 'a test of some preparation was to be made for which the astonishing claim had been made that it would render the person operated upon free from pain.'

"Those present were incredulous, and, as Dr. Morton had not arrived at the time appointed and fifteen minutes had passed, Dr. Warren said with significant meaning: 'I presume he is otherwise engaged.' This was followed by a derisive laugh and Dr. Warren grasped his knife and was about to proceed with the operation.

"At that moment Dr. Morton entered a side door. Dr. Warren turned to him and in a strong voice said: 'Well, sir, your patient is ready.' In a few minutes he was ready for the surgeon's knife, when Dr. Morton said: '*Your* patient is ready, sir.'

"Here the most sublime scene ever witnessed in the operating room was presented, when the patient placed himself voluntarily upon the table, which was to become the altar of future fame . . . That was the supreme moment for a most wonderful discovery. Had the patient died under operation, science would have waited long to discover the hypnotic effects of some other remedy [than ether] of equal potency and safety. It may be properly questioned whether chloroform would have come into use as it has at the present time.

"The operation was for a congenital tumor [a growth existing at birth] on the left side of the neck . . . The operation was successful; and when the patient recovered, he declared he had suffered no pain. Dr. Warren turned to those present and said: 'Gentlemen, this is no humbug.' "

Morton and Jackson, joining forces, tried to patent ether under the name of

Letheon. They proposed to issue permits for a considerable fee to physicians who wished to use the new anesthetic. This scheme was doomed to failure as soon as doctors recognized that Letheon was simply sulfuric ether. Morton and Jackson soon parted company. Each of the former partners insisted that he was the sole discoverer of anesthesia. That honor was also claimed by Horace Wells, who, as we saw, had used nitrous oxide as an anesthetic.

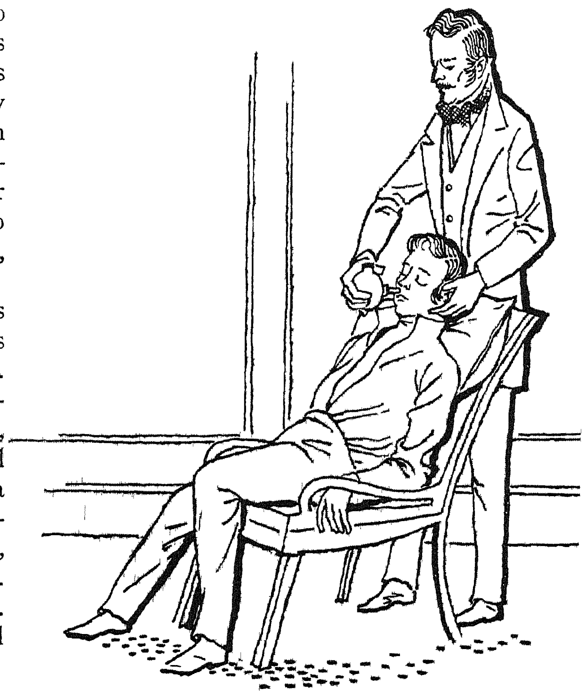
In 1849, Morton petitioned Congress to give him a substantial reward for his work in developing a safe anesthetic. Jackson also pressed his claims before Congress; the friends of Wells, who had died, likewise entered the lists. For several years the controversy raged. At last a measure appropriating $100,000 for Morton was being actively pushed in the Senate, when one of the senators rose to protest. He pointed out that Dr. Crawford W. Long (1815–78), of Georgia, had used ether in a surgical operation in 1842 — four years before the historic demonstration at the Massachusetts General Hospital. Long's patient, James Venable, had declared under oath in 1849:

"In the early part of the year [1842] the young men of Jefferson and the country adjoining were in the habit of inhaling ether for its exhilarating powers. I inhaled it frequently for that purpose and was very fond of its use.

"While attending the academy, I was frequently in the office of Dr. C. W. Long, and having two tumors on the back of my neck, I several times spoke to him about the propriety of cutting them out, but postponed the operation from time to time. On one occasion . . . I agreed to have one tumor cut out and had the operation performed that evening after school was dismissed. This was in the early part of the spring of 1842.

"I commenced inhaling the ether before the operation was commenced and continued it until the operation was over. I did not feel the slightest pain from the operation and could not believe the tumor was removed until it was shown to me."

Congress took no further action on the $100,000 appropriation after Venable's affidavit had been revealed. To this day the question of priority in the matter of the discovery of anesthesia is shrouded in doubt. It is important to observe that Venable's affidavit was not given until 1849, three years after Morton's public demonstration. The only compensation that Morton ever received for his work on anesthesia was an honorary degree from an American university and a gold medal from the French Academy of Sciences. He died poor and embittered in 1868.



Dr. William T. G. Morton administering ether to a patient before an operation.

The news of the successful use of ether as an anesthetic flashed quickly around the world. British surgeons, notably James Syme, the tutor of Lister, and James Y. Simpson (1811–70), professor of obstetrics at the University of Glasgow, hastened to adopt this new medical procedure; so did eminent surgeons in other lands.

On November 4, 1847, Simpson announced that chloroform, which had been

discovered by the French chemist Jean-Baptiste-André Dumas, could also be employed as a safe anesthetic; he had used chloroform to ease the pains of a woman in childbirth. Simpson was greeted by a perfect hail of criticism. He was denounced by clergymen and others who claimed that painless childbirth was a violation of God's will. They quoted Scripture (Genesis, III:16): "Unto the woman [God] said, I will greatly multiply thy pain and thy travail; in pain thou shalt bring forth children." Simpson answered these objectors in 1847 in a famous paper called Answers to the Religious Objection against the Employment of Anesthetic Agents in Midwifery and Surgery. He failed to silence his critics. But then, in April 1853, Queen Victoria consented to take chloroform during the birth of her seventh child, Prince Leopold. The opposition to pain-killing in childbirth collapsed as if by magic. Chloroform was often administered to women in childbirth thereafter. Nowadays, however, most obstetricians favor so-called "natural childbirth."

THE GERM THEORY OF DISEASE

For many centuries mankind had lived in constant fear of epidemics — a fear that was aggravated by a sense of utter helplessness. The germ theory of disease did much to free man from this terrible nightmare of dread. The theory was one of the great scientific triumphs of the nineteenth century — indeed, of all time.

It had a strange and humble origin — the study of fermentation. Men had been making and drinking alcoholic beverages since time immemorial. Yet not until after the middle of the nineteenth century did anyone know the why and wherefore of fermentation, which turns grapes into wine, and hops, malt, rice, barley and other cereal grains into beer, ale and mead. The chemists of the early nineteenth century, led by Liebig, had said that fermentation was a chemical reaction.

The French chemist Louis Pasteur showed that it was due to the activity of certain living organisms, called bacteria. Continuing his study of bacteria, he launched his truly epoch-making theory that some of these tiny creatures — also called microbes, or germs — could overwhelmingly invade the human or animal body and thus cause disease.

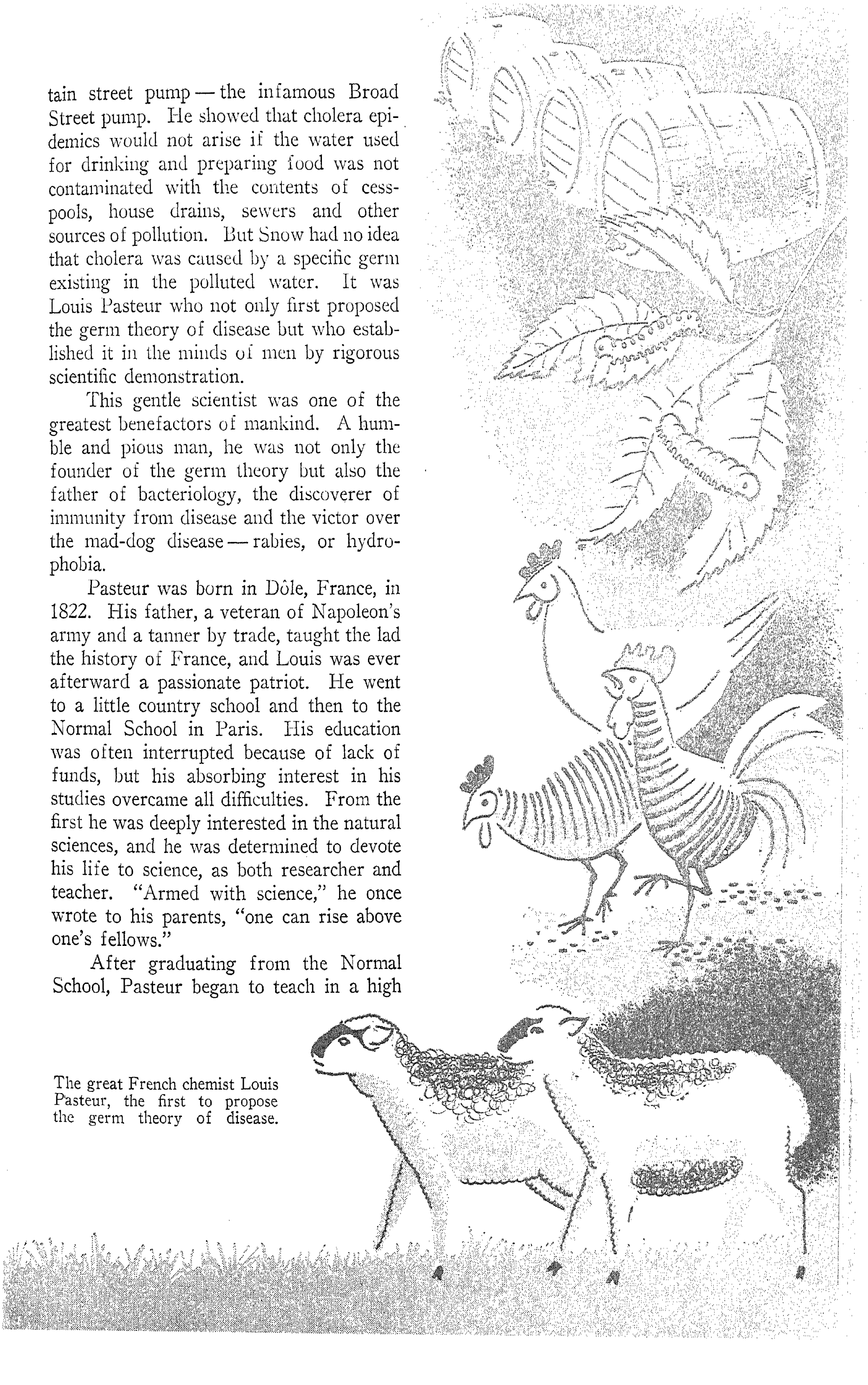
Today this theory is almost universally accepted. But until Louis Pasteur entered the scene, certain learned professors were still maintaining that earthquakes brought on the plague; and others attributed fevers to such factors as marshes, night air and bad odors. A few men, indeed, had at least some idea of the true facts in the case. The sixteenth-century Italian physician Fracostoro (see page 787) had expressed his belief in "seeds of contagion." John Snow (1813–58), a Yorkshire-born London physician, almost hit upon the truth when he traced a cholera epidemic in London in 1854 to the polluted water of a cer-

tain street pump — the infamous Broad Street pump. He showed that cholera epidemics would not arise if the water used for drinking and preparing food was not contaminated with the contents of cesspools, house drains, sewers and other sources of pollution. But Snow had no idea that cholera was caused by a specific germ existing in the polluted water. It was Louis Pasteur who not only first proposed the germ theory of disease but who established it in the minds of men by rigorous scientific demonstration.

This gentle scientist was one of the greatest benefactors of mankind. A humble and pious man, he was not only the founder of the germ theory but also the father of bacteriology, the discoverer of immunity from disease and the victor over the mad-dog disease — rabies, or hydrophobia.

Pasteur was born in Dôle, France, in 1822. His father, a veteran of Napoleon's army and a tanner by trade, taught the lad the history of France, and Louis was ever afterward a passionate patriot. He went to a little country school and then to the Normal School in Paris. His education was often interrupted because of lack of funds, but his absorbing interest in his studies overcame all difficulties. From the first he was deeply interested in the natural sciences, and he was determined to devote his life to science, as both researcher and teacher. "Armed with science," he once wrote to his parents, "one can rise above one's fellows."

After graduating from the Normal School, Pasteur began to teach in a high



The great French chemist Louis Pasteur, the first to propose the germ theory of disease.

school in Paris; in due course he married the principal's daughter. His researches on the structure of crystals attracted wide attention and won him a professorship of chemistry at the new University of Lille. As a university professor, Pasteur was a civil servant. The Government did not hesitate to call upon him to help businessmen and others who had problems that could be solved more or less readily by chemical methods.

Soon Pasteur was requested to find out why the wine in Orléans was turning sour. After careful research, he discovered that fermentation was brought about through the activities of certain minute organisms. He showed the vintners how to keep their wine from spoiling by gently heating it to a temperature of 55 degrees centigrade — the process that we now call pasteurization. The heating destroys the tiny organisms that sour wine, beer and milk. "I found," wrote Pasteur, "that all real fermentations depended on the presence and multiplications of organic beings [that is, bacteria]."

The chemists of the old school were unconvinced; they maintained that fermentation was a chemical phenomenon and that living things like microbes had nothing to do with it. "Where did these microbes come from?" they asked. "They are found in the air," was Pasteur's response. He now devised an experiment that silenced his opponents. First he caused air to be sucked through a tube filled with cotton wool. The dust particles that collected in the tube were transferred to a sterile sugar solution in a gooseneck flask. The neck was then sealed. In a few days great colonies of bacteria were found inside the sealed flask. Obviously these colonies had descended from the original bacteria drawn from the air. Pasteur showed also that if the dust and sugar solution in the flask was boiled, no bacteria grew. He won a prize — and many adherents to his new germ theories — as a result of the crucial experiments.

Another practical problem was now thrown into his lap. The silkworms in Alais (Alès) were dying of a mysterious disease and the silk industry of southern France was in danger of extinction. His old teacher, the chemist Jean-Baptiste-André Dumas, begged him to investigate the problem. "I have never had anything to do with silkworms," protested Pasteur; but in the year 1865, he packed his trusty weapon, the microscope, and went south to attack this new problem.

By 1871 (the year the victorious Prussians entered Paris) Pasteur had discovered that the silkworms were dying not from one disease but from two. Even more important, he showed that each of these diseases was caused by a specific microorganism. Pasteur devised a method for preventing contagion as well as for detecting diseased silkworms — and the silkworm industry was saved.

Pasteur now turned his attention to the study of the germs causing chicken cholera and anthrax. He cultivated the germs of chicken cholera in a kind of chicken soup — a culture medium in which the microbes could find suitable food. One day he injected an old, stale culture into a few hens. The fowl became slightly sick but soon recovered. Then it occurred to him to inject fresh, germ-full cultures into the hens. Nothing happened. In some unique way, the old, thinned out cultures had strengthened the hens' defenses against infection with fresh germs. This is an example of the phenomenon of immunity, or the mobilization of the body's defenses against bacterial invaders.

In May 1881, Pasteur and his associates proved that immunity to anthrax could also be acquired. In a demonstration at a farm near Melun, twenty-five sheep and six cows were injected with vaccines made from old cultures of the anthrax bacillus (germ). An equal number of cows and sheep were not vaccinated. Then all the animals were infected with living anthrax germs. To the astonishment of the veterinarians and farmers who were following the experiment, the vaccinated sheep and cows remained in excellent health, while all the unvaccinated animals quickly sickened and died.

Pasteur's researches in the dread dis-

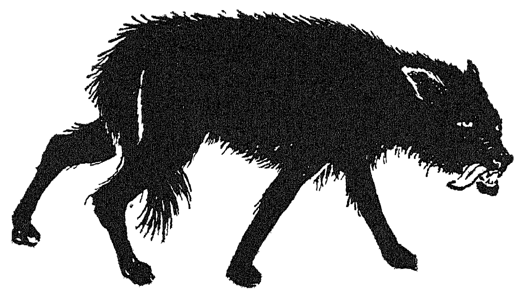
ease called hydrophobia, or rabies, made a particularly dramatic story. Hydrophobia attacks many animals, including dogs, cats, wolves, foxes and jackals; it is transmitted to man by the bite of infected animals. The most striking feature, perhaps, of the disease is shown at an advanced stage. The patient is tormented by thirst and yet is seized with a violent choking fit when he attempts to swallow water. In fact, the very thought of water may bring on such an attack; hence the name "hydrophobia" ("fear of water," in Greek). Until Pasteur, hydrophobia victims always died after suffering the most frightful agonies.

After extended experiments with saliva from infected animals, Pasteur came to the conclusion that the germ — or as it later turned out, the virus — of the disease was concentrated in the nerve centers of the victims. He found, for example, that when he introduced matter from the spinal cord of an infected dog into a healthy animal, he could produce the symptoms of hydrophobia. He also discovered that he could prevent dogs from dying of the disease by a series of injections of the dried spinal cords of infected rabbits.

On the morning of July 6, 1885, a nine-year-old Alsatian lad, Joseph Meister, who had been cruelly bitten by a mad dog, was brought to Pasteur's laboratory in Paris for treatment. Pasteur had never tried his vaccine on a human being, and he hesitated to do so now. "The death of this child," he wrote afterwards, "appearing to be inevitable, I decided, not without lively apprehension, as may well be believed, to try upon Joseph Meister the method that I had found constantly successful with dogs." The treatment proved to be entirely successful; the boy speedily recovered.

Soon Pasteur was besieged by patients from all over the world, seeking treatment for the bites of mad dogs and wolves. A grateful world honored the great scientist's name by contributing funds to build a series of Pasteur Institutes, where vaccine could be manufactured, treatments given and research on immunization undertaken.

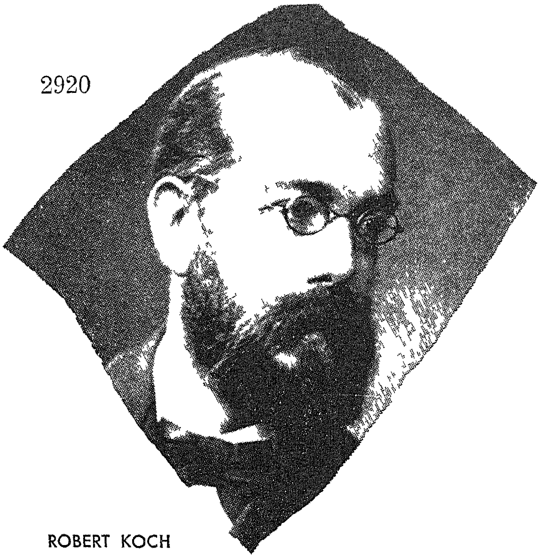
Pasteur died quietly, full of years and honors, in 1895. His career emphasizes an



important point: that efforts to solve immediate and practical problems of industry may lead to the discovery of immensely valuable theories in pure science. Thus Pasteur's work on the problems of vintners and silkworm-growers in France led to the establishment of the germ theory of disease, the science of bacteriology and the doctrine of immunization.

The world of science and the general public eagerly accepted Pasteur's demonstration of the thesis that tiny organic beings cause disease — that is, the germ theory of disease. In the first flush of enthusiasm, it was thought that all diseases were probably germ diseases; but twentieth-century physicians have come to recognize that this is not the whole story. There are many important classifications of disease for which no "germ" can be found; for example, heart disease, cancer, and a host of psychosomatic (mind-body) ailments, in which the effect of emotions on bodily states is the predominating factor. We know now that the causes of disease are multiple. To understand and control them, we must study the host of the disease (that is, the sick person), the agent of disease (which may be, but is not always, a germ) and the environment of both.

After Pasteur, the science of bacteriology, dealing with the study of bacteria, moved ahead at an exciting pace and for perhaps half a century dominated all thinking about the nature of disease and the means of preventing it. There were two trails leading to the conquest of communicable diseases — one the bacteriological trail, uncovering the specific agents of specific diseases; the other, the epidemiological trail, noting and finding means of preventing the transmission of disease. Often these trails overlapped as the microbe



ROBERT KOCH

hunters discovered both new agents of disease and unexpected methods of transmission.

Perhaps the greatest microbe hunter after Pasteur was Robert Koch (1843–1910), a German doctor. He was an exceedingly painstaking man of science, who established a series of postulates, or rules, for determining the identity and the specific character of disease germs. He discovered how to stain bacteria with dyes so that they could be seen and studied under the microscope. He isolated and described the anthrax germ in 1876; in 1882 he discovered the tubercle bacillus, the germ that causes tuberculosis; in the following year he identified the comma bacillus, the germ of Asiatic cholera.

Koch electrified the whole world in 1890 by announcing that he had discovered a substance — tuberculin — that could cure tuberculosis. Koch had prepared this substance by sterilizing the medium in which tubercle bacilli were grown in the laboratory, filtering it and concentrating it by evaporation. It soon became evident that tuberculin could not live up to the extravagant claims that Koch had made for it as a cure for tuberculosis. Eventually, however, it proved to be useful in diagnosing the disease, and it is employed for this purpose at the present time. Despite the failure of his tuberculosis "cure," Koch continued to enjoy the esteem of the scientific world. He investigated many other diseases — notably African sleeping sickness. In 1905 he was awarded the Nobel Prize in medicine.

Other microbe hunters made notable finds in the exciting final quarter of the nineteenth century Armauer Gerhard Henrik Hansen discovered the bacillus causing leprosy in 1874; this germ is often referred to now as Hansen's bacillus. In 1879, Albert Ludwig Siegmund Neisser isolated the gonococcus, the germ that causes gonorrhea. In the following year the bacillus of typhoid fever was identified by Karl Joseph Eberth. In 1881, George Miller Sternberg in the United States and Karl Fraenkel in Germany discovered the bacterium that causes lobar pneumonia; the great Pasteur isolated this germ at about the same time The bacillus causing diphtheria was first described by Edwin Klebs in 1883 and isolated by Friedrich August Johannes Loeffler in 1884. Arthur Nicolaier discovered the bacillus of tetanus (lockjaw) in 1894.

Once the agents that caused communicable diseases were discovered, it became imperative to find out how they were transmitted. It was found that certain hosts will harbor the bacilli of specific diseases It was also demonstrated that certain kinds of food and drink could carry and transmit disease germs. Thus, the burly British doctor David Bruce (1855–1931) found out in 1887 that the microbes of Malta fever, or undulant fever, can be carried in goat's milk. The disease is transmitted to humans when such infected milk is drunk Undulant fever can be transmitted from cow's milk; milk derived from tubercular cows can also infect human beings with tuberculosis. That is one reason why we insist on pasteurized and certified cow's milk today.

It was discovered by nineteenth-century microbe hunters that insects also transmit disease germs. Men had long suspected that the fly was a vector (carrier) of disease; but the guilt of the insect was first definitely established in 1869, when it was demonstrated that the fly carries the germs of anthrax. Four years later an English nurse, who was in the Near East

during a cholera epidemic, noted that the epidemic abated when flies vanished. In Washington, D. C., it was shown that these insects carried the germs of typhoid fever from insanitary privies to kitchens and parlors. A United States Army Medical Commission report revealed that flies carrying typhoid fever had killed more soldiers than bullets had killed during the Spanish-American War.

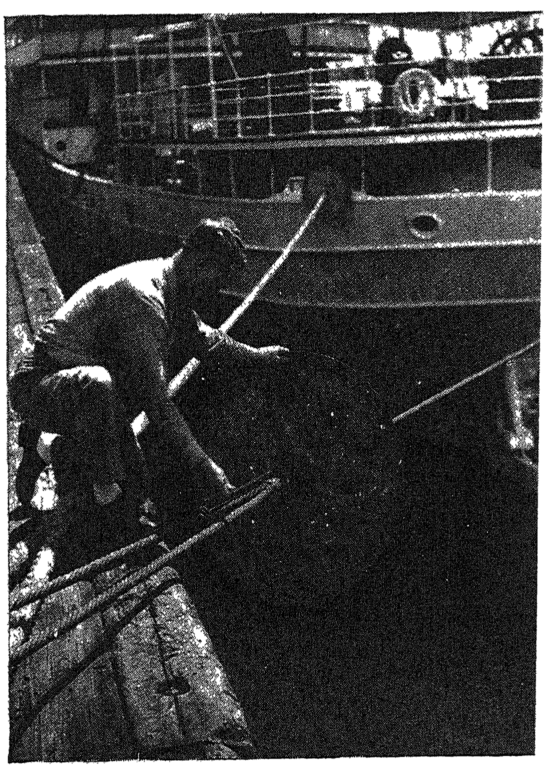
Fleas turned out to be another vector of disease. In 1894 the Japanese Shibasaburo Kitazato and the Swiss Alexandre-Emile-John Yersin discovered the bacillus of bubonic plague in the fleas that infest rats. International health activities have done much to protect the world from this ancient scourge; but it has not yet been exterminated. Plague bacilli have also been found in the fleas that infest the rats' fellow rodents, particularly the ground squirrel.

The story of how the tick was proved to be the vector of Texas fever is particularly engrossing. It carries us to the Old Chisholm Trail, over which Texas cattle were driven north for fattening and marketing. The hero of this tale was a city-born doctor, Theobald Smith (1859–1934), an employee of the United States Bureau of Animal Industry in Washington, D. C.

The bureau had been called upon to solve a serious problem confronting the cattlemen of the West. When southerners brought their cattle northward and set them to graze together with northern cattle, the southern cattle remained fat and healthy. But the northern cattle, after a month or so, took sick with the disease called Texas fever. They stopped eating, lost weight and died. Why? Smith went out west to solve the mystery. Cowpunchers, he found, claimed that the disease was due to ticks. Smith sought to find out whether or not this was the case.

It was a strange laboratory in which he worked; it consisted of six dusty fenced-off fields, in which there were northern cows, southern cows and ticks. Some ticks were so small that they could be detected only with a magnifying glass; others — big female ones gorged with cow's blood — were half an inch long. Through microscopes Smith and his co-workers spotted little pear-shaped microbes in the blood cells of sick cows and in the bodies of the ticks. But ticks have no wings; they do not jump from cow to cow; they live their whole lives on a single host. How then can ticks carry Texas fever from a Texas cow to a Montana cow? Smith pondered the question.

One hot summer day in 1890 he found the answer. After infesting southern cattle, adult female ticks dropped to the ground where they laid microbe-infected eggs. In about three weeks, the eggs became baby ticks whose bodies and stingers harbored the microbes of Texas fever. When a baby tick crawled up a northern cow's leg and bored its way in, it carried the fever germs with it. The southern



USPHS

Rat guards are placed on the mooring lines of ships coming from plague-infested ports. Rats may harbor the fleas that transmit bubonic plague.

cows, source of the infection, did not become sick because they had developed an immunity to the disease.

In 1893 Smith issued a report on his findings, called INVESTIGATIONS INTO THE NATURE, CAUSATION AND PREVENTION OF TEXAS OR CATTLE FEVER. His solution of the Texas fever problem was a simple one. "Dip your cattle clean; kill the ticks," he said, "and the disease will disappear." Later investigations have shown that ticks also carry germs of diseases — like Rocky Mountain spotted fever — that attack man.

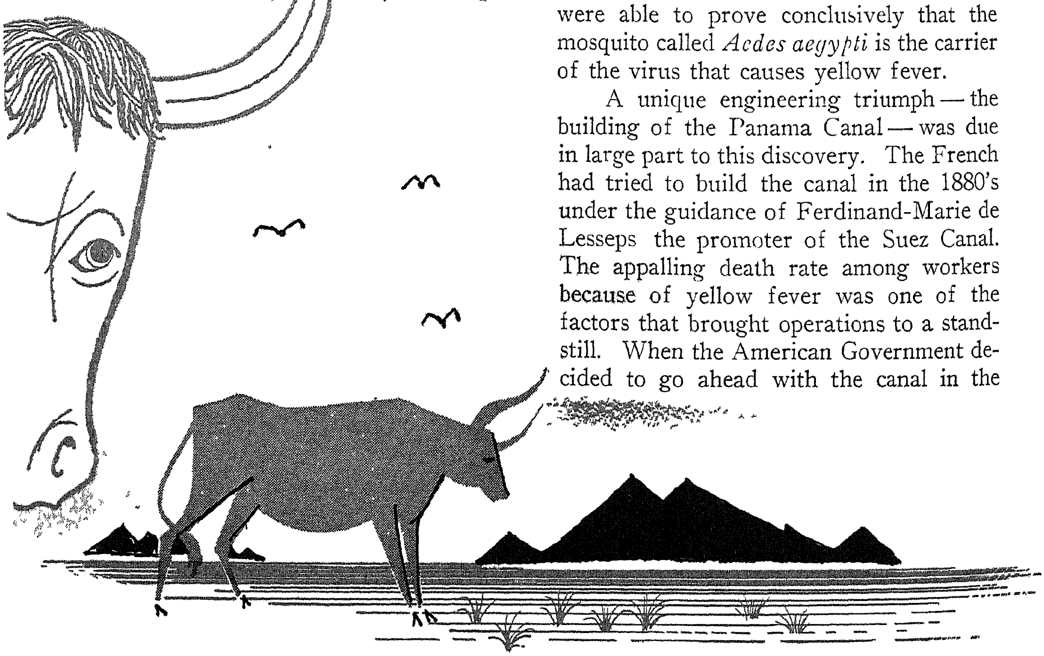
Smith had opened the way to a whole new field of inquiry in the matter of disease control — the sciences of epidemiology and preventive medicine. He put David Bruce on the trail of the tsetse fly, which turned out to be the vector of African sleeping sickness in horses, wild animals and men. Most important, he influenced the men whose work put the mosquito at the top of the list of insect vectors of disease.

The mosquito is the vector of the most prevalent disease on the face of the globe — malaria. This fact was brilliantly demonstrated, just before 1900, by the British poet-physician Sir Ronald Ross (1857–1932), serving in the Indian Medical Service, and the Italian physician Giovanni Battista Grassi (1854–1925). Mosquito control is the essence of malaria control. Only a few species of mosquitoes, of course, carry disease.

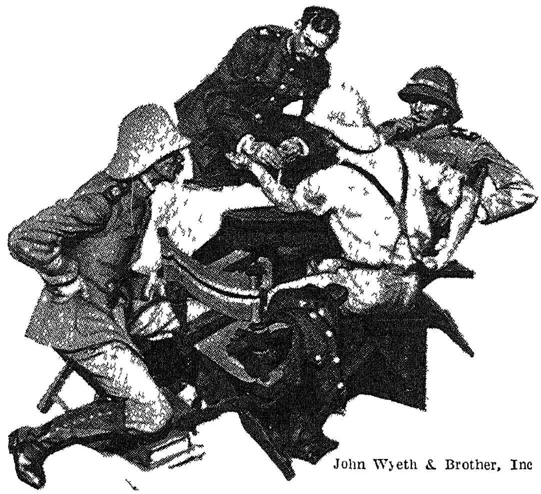
A dramatic demonstration of the role of the mosquito in carrying disease occurred in the case of yellow fever, sometimes called yellow jack. Havana, Cuba, was infested with the disease. A Cuban physician, Carlos Juan Finlay (1833–1915), suspected that the mosquito might be the carrier of the disease, but he could never definitely prove that his theory was correct. Following the Spanish-American War of 1898, the United States took over Cuba, formerly a Spanish possession, and faced the problem of combating yellow fever.

The United States Army sent a distinguished commission to Cuba to investigate the disease. It was headed by Major Walter Reed (1851–1902) and included Dr. Jesse William Lazear, who died a martyr to the investigation. At a crucial point in the proceedings, it became necessary to find human volunteers who would risk contracting yellow fever. Two soldiers and one civilian employee of the Army offered themselves without pay for this experiment, acting, as they said, "solely in the interests of science and for humanity." With the help of these volunteers and other devoted men, Reed and his associates were able to prove conclusively that the mosquito called *Aedes aegypti* is the carrier of the virus that causes yellow fever.

A unique engineering triumph — the building of the Panama Canal — was due in large part to this discovery. The French had tried to build the canal in the 1880's under the guidance of Ferdinand-Marie de Lesseps the promoter of the Suez Canal. The appalling death rate among workers because of yellow fever was one of the factors that brought operations to a standstill. When the American Government decided to go ahead with the canal in the



America's Reed Commission investigated yellow fever in Cuba.



John Wyeth & Brother, Inc

early 1900's, it was recognized that the first job to be tackled was that of cleaning up the Canal Zone The task was entrusted to Colonel William C. Gorgas (1854–1920). He knew how yellow jack was carried; he kept down the mosquito population and the canal was pushed through

We can look upon the Panama Canal as a monument to the devoted men who demonstrated that *Aedes aegypti* carries yellow fever; to Theobald Smith, who showed how insect vectors could be tracked down; to Louis Pasteur, who gave the world the germ theory of disease.

SURGICAL OPERATIONS BECOME SAFER

Modern surgery is based upon anesthesia and asepsis. The word asepsis means complete exclusion of disease-producing bacteria in order to prevent infection. This idea, based on the germ theory of disease, was new to the nineteenth century. Before asepsis came antisepsis — the process of actually killing microbes by application of chemicals.

The man who brought antiseptic methods into surgery was a gentle, clear-eyed and high-minded Quaker wound-dresser, Joseph Lister. He was born at Upton, in the English county of Essex, in 1827, the son of a wine merchant who devoted his leisure hours to making microscopes. Lister attended the Quaker schools at Hitchin and Tottenham; he then studied medicine at University College, in London. After completing his medical course, he went to Edinburgh armed with an introduction to the eminent Scottish surgeon James Syme (1799–1870), professor of clinical surgery at the University of Edinburgh. Lister became a house surgeon under Syme; three years later he married Syme's daughter.

Lister was appointed professor of surgery in Glasgow in 1860. He was particularly interested at that time in the infections that originated in wounds and that caused the formation of pus — "laudable pus," the surgeons of that time called it, because it was supposed to be a sign of healing. What was the source of the putrefaction — that is, the infection — that caused the formation of pus?

In 1865 a colleague of Lister called his attention to Pasteur's demonstration that putrefaction is caused by microbes present in the air. It occurred to Lister that, if such were the case, one might be able to prevent surgical infection and the consequent formation of pus by killing the microbes. For this purpose, Lister decided to use carbolic acid, which had served previously to disinfect sewage. He painted the wound of a patient suffering from a

compound fracture with undiluted carbolic acid and then dressed it with cloths that had been dipped in diluted acid. The wound healed beautifully. In the course of the following two years Lister used this method on many patients with excellent results.

On August 9, 1867, he reported on the method at a meeting of the British Medical Association in Dublin. "I left behind me at Glasgow," he said, "a boy, thirteen years of age, who, between three and four weeks previously, met with a most severe injury to the left arm, which he got entangled in a machine at a fair . . . Without the assistance of the antiseptic treatment, I should certainly have thought of nothing else but amputation at the shoulder joint . . . Now I did not hesitate to try to save the limb by wrapping the arm from the shoulder to below the elbow in the antiseptic application . . . Before I left, the discharge was already somewhat less, while the bone was becoming firm . . . I feel sure that if I had resorted to ordinary dressing when the pus first appeared, the progress of this case would have been exceedingly different." In other words, the injured boy would have lost his arm.

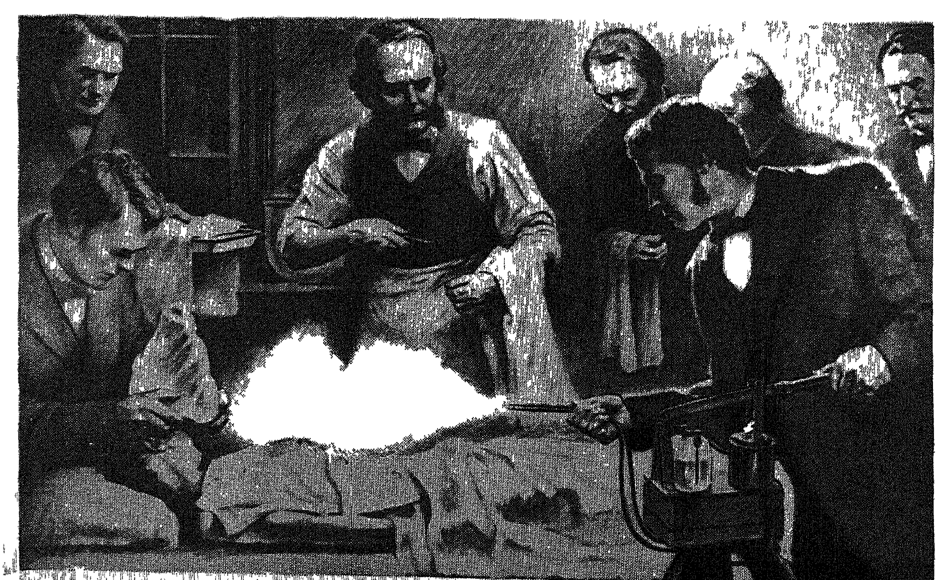
Lister ended his address by pointing to the revolution that the introduction of antisepsis had brought in hospital methods of treatment. "Previously to [the introduction of antisepsis]," he said, "the two large wards in which most of the cases of accident and operation are treated, were among the unhealthiest in the whole surgical division of the Glasgow Royal Infirmary . . . I have felt ashamed when recording the results of my practice to have so often to allude to hospital gangrene and pyemia [pus in the blood stream] . . .

"But since the antiseptic treatment has been brought into full operation, and wounds and abscesses no longer poison the atmosphere with putrid exhalations, my wards, though in other respects under precisely the same conditions as before, have completely changed their character. During the last nine months not a single instance of pyemia, hospital gangrene or erysipelas [inflammation of the skin] has occurred in them."

Since undiluted carbolic acid irritates the tissues of the body, Lister mitigated its effects by blending it with shellac. In

Joseph Lister supervising the use of dilute carbolic acid, in the form of a spray, in one of the earliest "antiseptic" surgical operations.

Bettmann Archive



order to get rid of the germs that might be floating around in the operating room, he used a spray apparatus to disinfect the air with a dilute solution of carbolic acid. Lister and other surgeons soon saw that it was not essential to kill germs in the air — a possible but unlikely source of wound infection in the operating room. It was only necessary to take sensible precautions to keep germs away from the operative wounds and the surgical field. This could be done by sterilizing all the instruments used in operations, by using sterile clothing and by keeping the hands aseptically clean. Surgery moved from antisepsis to asepsis.

Lister won the respect and esteem of the men of his generation. He was President of the Royal Society from 1895 to 1900; in 1897 he was raised to the peerage as Baron Lister of Lyme Regis. When he died, in 1912, he was buried in Westminster Abbey, reserved for Britain's greatest men. His chief monument, perhaps, is the Lister Institute of Preventive Medicine in London, modeled after the Pasteur Institute of Paris.

With the advent of anesthesia, antiseptics and scrupulous cleanliness in the operating room, surgeons all over the world began cutting into the human body more deeply than ever before. They penetrated the abdomen; many surgeons devised elaborate operations which they named after themselves. Soon all the organs in the abdomen — the stomach, the gall bladder, the pancreas, the intestines and the appendix — could be operated on successfully. Countless human lives were saved as a result. For example, before Lister's time, appendicitis (inflammation of the vermiform appendix) had probably been about as common as it is today. But surgeons had never operated on the appendix, and the patient had always died. With the perfection of abdominal surgery, an appendectomy (removal of the appendix) became a relatively simple operation.

Later developments made it possible for the surgeon to invade the chest cavity, where the lungs and heart are located. In the twentieth century, surgeons found safe ways of getting deep into the skull cavity.

Standard Oil Co. (N.J.)

Surgeon removing a patient's tonsils in a modern clinic.

The great American surgeon Harvey Cushing (1869–1939) finally reached the pituitary body, a small gland that lies at the very base of the brain. The ancients had considered this gland or a nearby one — the pineal — as the "seat of the soul." Actually, the pituitary gland exerts a great effect upon the chemistry of the human body — and particularly on the reproductive system.

The advancing science of surgery gave new impetus to pathology — the study of diseased tissues. Toward the end of the eighteenth century, the problem of tissue changes in disease had been attacked by Marie-François-Xavier Bichat (1771–1802), who had served as a surgeon to the armies of the French Revolution. An appointment as physician to a famous hospital, the Hôtel-Dieu in Paris, gave him the opportunity to perform numerous autopsies. In a period of six months he opened some six hundred bodies in order to study the changes brought about in human tissues by disease.

The man who put pathology on a modern footing was a vigorous little German anatomy professor, Rudolf Virchow (1821–1902). He was perhaps the greatest medical figure in Berlin in the last half of the nineteenth century. He made many important contributions to histology (the science of tissues) and to the study of various

diseases. In his book Cellular Pathology, published in 1858, Virchow gave a striking account of what happens in disease states.

Virchow was probably the first to point out that white blood cells — leucocytes — mobilize to defend the injured part of a body. The Russian-born bacteriologist and zoologist Elie Metchnikoff (1845–1916) later explained that the white cells gobble up germ invaders. He found a fine mouth-filling word for this process: "phagocytosis" ("cell-eating process," in Greek). Metchnikoff's work on immunity won him a Nobel Prize in medicine (with Paul Ehrlich) in 1908. This many-sided scientist made a study of syphilis and prescribed calomel ointment as a protection against it. He was also interested in gerontology — the science that studies the process of growing old. It has taken on added importance in our own day. A world made safer by surgery and sanitation contains far more old people than ever before.

"THE QUALITY OF MERCY IS NOT STRAIN'D"

"The quality of mercy is not strain'd
It droppeth as the gentle rain from heaven
Upon the place beneath."

These magnificent lines from Shakespeare's Merchant of Venice apply admirably to the noble profession of nursing. It is hard to realize that until about the middle of the nineteenth century, nurses (except for women in religious orders) were held in almost universal scorn. As the London Times put it, in 1857: "Lectured by committees, preached at by chaplains, scowled on by treasurers and stewards, scolded by matrons, bullied by dressers, grumbled at and abused by patients, insulted if old and ill-favored, talked flippantly to if middle-aged and good-humored, seduced if young — they are what any woman would be under the same circumstances." They were, generally, disreputable, dowdy and, all too often, drunken.

This sad state of affairs was changed chiefly through the efforts of a high- (and strong-) minded Victorian lady, Florence Nightingale (1820–1910). Through her ideas and ideals, her widely heralded errands of mercy and her skill as an administrator she made nursing a highly honored profession.

A gentlewoman by birth, Florence Nightingale received an excellent classical and mathematical education at home with her father as teacher. Instead of settling down thereafter to the conventional life of an aristocratic young lady, she shocked her friends by showing a deep interest in nursing.

FLORENCE NIGHTINGALE

She underwent a regular course of training as a nurse at the Institute of Protestant Deaconesses, located at Kaiserswerth, Germany, and operated by Pastor Theodor Fliedner. After she had completed the course, she underwent further training in hospitals in London and Edinburgh and studied nursing problems in London.

Miss Nightingale's opportunity to show the world the need of scientific methods in nursing came in 1854 during the Crimean War. The scene of the fighting was the Crimea, a peninsula on the Black Sea; the British and French were pitted against the Russians. After the manner of poets, Tennyson later glamorized a relatively minor episode of the war — the charge of the Light Cavalry Brigade at Balaklava. But as a matter of fact, there was precious little glamour in the Crimean War. The fighting was bitter; losses were heavy; the suf-

ferings of the wounded and sick on both sides aroused the horror of the world. "The soldier knew some one had blundered," wrote Tennyson of the order that sent the gallant Light Brigade "onward into the valley of death." But the chief English blunderers were those who had failed to provide suitable medical care for the British Army.

Conditions at the British base hospital at Scutari (Üskudar, Turkey) were abominable. The alleged hospital was a dirty, stinking yellow barn, infested with rats and vermin and without any comforts or conveniences. When British war correspondents revealed these conditions, there was a great public protest, and a royal commission of inquiry was set up. Florence Nightingale wrote to her friend Sidney Herbert, the War Secretary, offering her services and he gladly accepted them. Accompanied by thirty-eight trained "sisters of mercy," she set sail on October 21, 1854, and two weeks later arrived at Scutari. Miss Nightingale and her associates went to work immediately; they scrubbed, they washed, they re-arranged, they cooked for the sick and wounded. The sight of Florence Nightingale walking through the wards late at night with a lamp in her hand, inspecting and comforting, became an inspiration to the patients and to the nurses who worked with her.

The "Lady with the Lamp" had much to contend with. The military authorities resented what they considered her interference. They did what they could to thwart her, but she had the backing of the War Secretary and she overcame all obstacles. The results were truly astounding. In February 1855 the death rate in the hospital was 42 per cent; by June it had dropped to 2 per cent.

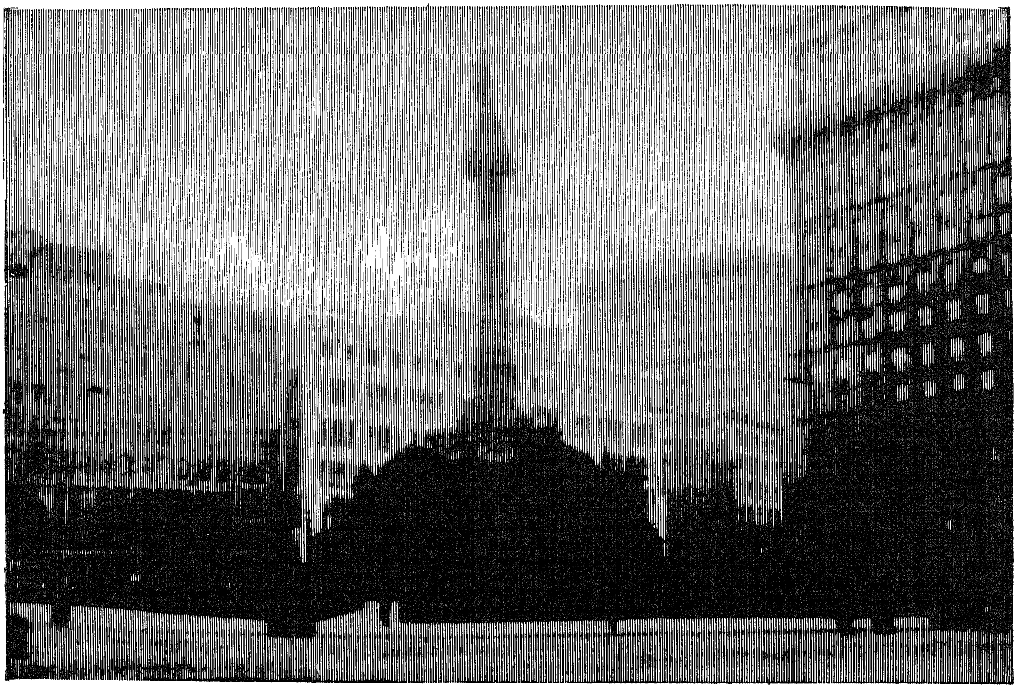
Upon her return to England in 1856, Florence Nightingale founded the Nightingale Home for Training Nurses at St. Thomas' Hospital, with a fund of £50,000 ($250,000), which had been raised by subscription in recognition of her services. Soon the nurses who had been trained at St. Thomas' were in great demand, and other nurses' training centers were set up in the United Kingdom. In time the ignorant and dirty slatterns who had served in the hospitals were replaced by well-trained and self-respecting women who inspired in the patient the will to live.

War, serving as a whip to mercy, had provided the impetus for Miss Nightingale's reform of the nursing profession. It also led to the formation of the Red Cross societies — those wonderful national organizations that seek to alleviate and prevent human suffering. The founding of the International Red Cross goes back to the year 1859, when the French and Sardinians fought a bloody battle at Solferino, Italy, against the Austrians. A young Swiss banker, Jean-Henri Dunant (1828–1910), was an eyewitness of the battle; after the fighting was over, he organized a corps of volunteers to search out and nurse the wounded left unattended on the field of battle. The experience touched him so deeply that in 1862 he struck off a pamphlet, called MEMOIR OF SOLFERINO, in which he proposed the formation of an international society to provide aid to the wounded and sick in wartime.

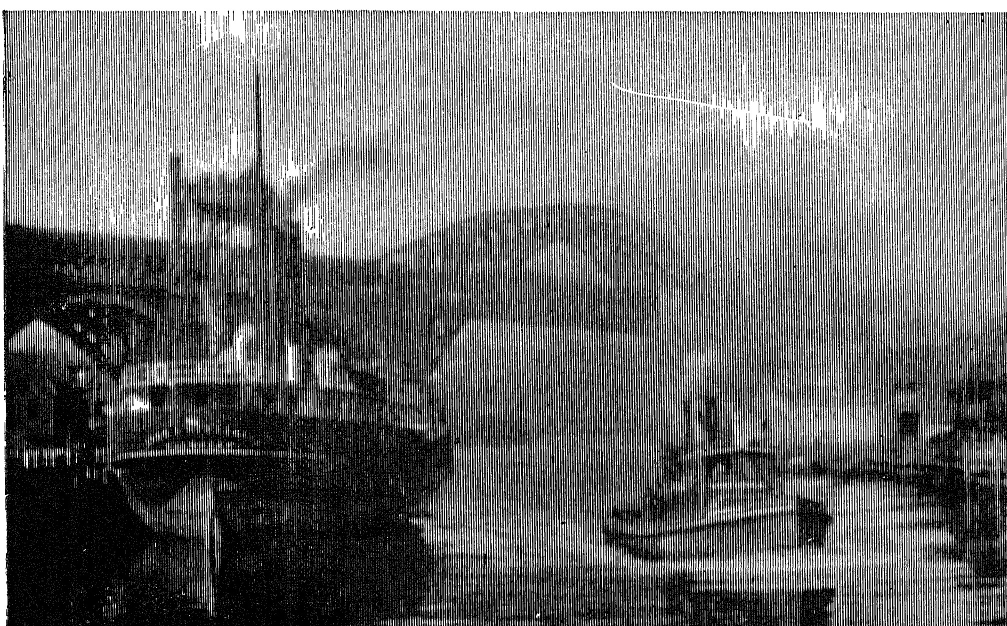
In 1864, a conference for this purpose was held at Geneva, with twenty-six delegates from sixteen governments attending. This conference, known as the Geneva Convention, witnessed the official birth of the Red Cross organization. Its identifying symbol was to be a square red cross on a white field — the flag of Switzerland reversed. This emblem was to be a sign of impartial help to both sides in a war; it was never to be fired upon. Since that time, the Red Cross societies have widened their scope by peacetime activities. They have provided relief in disasters; they have worked for public education in health matters, for public-health nursing and for improved health conditions generally.

Many other voluntary health agencies have also entered the lists to battle against disease and needless suffering. They bear eloquent testimony to the medical progress of the nineteenth century — progress that has brought new hope for happier, healthier living to mankind.

SCIENCE THROUGH THE AGES continues on page 3217.



SOLDIERS' MONUMENT AND PUBLIC SQUARE, CLEVELAND



HIGH LEVEL BRIDGE

These pictures were sent by long-distance telephone wire from Cleveland to New York.

PICTURE TRANSMISSION BY WIRE

A Development That Opens a New Field for Printing News Pictures

AN ELECTRICAL ENGINEERING MARVEL

ON May 19, 1924, exactly forty-four minutes after a picture was taken in Cleveland, Ohio, it was exhibited, completely developed, to a group gathered in a room of the American Telephone and Telegraph Company Building, New York, who had watched that picture being spun, flash by flash, upon the sensitive film of a complex machine.

Perfect in every detail, the photograph had been transmitted over long-distance telephone lines by a new system which is startling in its possibilities. Only five minutes were consumed in actual transmission of the picture, the rest being required for development purposes. The system is a development of the engineers of the American Telephone and Telegraph Company and the Western Electric Company, and it is the outcome of work covering several years. The apparatus in its present form represents the association of many recent inventions together with standard types of telephone and telegraph apparatus readapted to this new use.

The simplicity of the method is such that a positive transparency film supplied by any photographer is suitable for transmission. The apparatus is so designed as to transmit a picture five by seven inches in a little less than five minutes. The picture is received in such form that after photographic development of the usual sort, it is ready for newspaper or other reproduction. Line drawings, printings and handwriting can also be transmitted. As films can be used for transmission while still wet, this system eliminates the delay which would otherwise be caused by drying.

The process is as follows:

At the sending end there is a cylinder on which is wrapped a photographic film carrying a developed picture. On this is focused a beam of light which brilliantly illuminates an area one-hundredth of an inch square. This beam of light passes through the film and falls on a photo-electric cell which is mounted inside the cylinder. This device possesses the unique property of controlling the amount of electric current which can flow between the electrodes, in accordance with the amount of light reaching the interior of the bulb.

The electric current flowing through the photo-electric cell is amplified by vacuum tubes and is made to control the amount of current supplied to the telephone line. This current is transmitted over the line in the same manner as are the currents which carry the human voice in everyday telephone conversation.

At the receiving end of the telephone line this current is still further amplified and is made to operate a piece of apparatus known as a "light valve". The passage of the current received from the telephone line operates a little aperture, thus controlling the amount of light which passes through it. This light is brought to a focus on a cylinder corresponding to the one at the sending end of the line. The cylinder has wrapped upon it an unexposed photographic film, ready to receive the counterpart of the picture at the sending end.

By means of a special synchronizing system the cylinders at either end of the line are made to rotate at exactly the same speed, and by a screw mechanism the film is caused to advance parallel to the axis of the cylinder. The motion of the light

relative to the cylinder is therefore the same as that of a phonograph needle relative to a cylindrical record. This synchronizing system employs a control current which is transmitted over the same pair of wires which carry the "picture current". These two currents are kept apart at the receiving end by devices known as "filters". The control current is separately amplified and drives a small motor at precisely the same speed as a similar motor at the transmitting end. Thus, when the beam of light at the transmitting end passes through a particular spot on the transparent film the beam of light at the receiving end is focused on an exactly corresponding spot on the film being exposed.

The density of the film at the transmitting end of the line controls the amount of light which falls upon the photo-electric cell. This, in turn, controls the amount of current sent over the line. At the receiving end this current operates the light valve and thus determines the amount of light that falls on the unexposed film.

As the cylinders rotate the beam of light at the receiving end traces a spiral line around the cylinder. The width of this line at any point is determined by the density of the film at the corresponding point on the original picture at the sending end. Thus the effects of light and shade are achieved and the picture is reproduced in exact facsimile.

In the Wirephoto Service method, as developed by The Associated Press, an intense beam of light, five one-thousandths of an inch square, is reflected from a positive print on the sending cylinder to a photo-electric cell. A picture eight by ten inches is transmitted in eight minutes.

At the receiving end the amplified current from the sender operates a glow lamp which responds quickly to stronger or weaker impulses by glowing more or less brightly. This light is focused on an unexposed photographic film on a cylinder which turns like the one at the sending end.

Synchronization between sending and receiving cylinders is achieved by synchronous, constant speed motors at each end. These motors, continually turning, are controlled by electrical tuning forks of the same frequency. When sending is started a clutch mechanism engages simultaneously the motor and cylinder at each end.

THE FIRST PHOTOGRAPH SENT

AND AS RECEIVED

The broadcasting of photographs by radio and the reception of such pictures on a small and simple outfit in the home attached to the ordinary radio receiver in much the same manner as a loud speaker was publicly demonstrated for the first time by the National Broadcasting Company on January 26, 1928 The photographs were broadcast from New York over a high-power station at Belmore, L I, and were received at a distance of 25 miles from the transmitting antennae. Listeners tuned to WEAF during the picture transmission heard a wavering note or high-frequency squeal sustained for 90 seconds, the time required to send a picture 4½ × 8 inches.

ART OUT OF CHAOS

How the Dust of Mountains is Softened, Kneaded, Molded and Hardened into Things of Use and Beauty

POTTERY—THE WORLD'S OLDEST INDUSTRY

THE manufacture of pottery is the oldest and most universal of the creative industries of the world. Just as today rude forms of pottery are made by the tribes that remain in a state of savagery, so, among the buried records of the first men whom we can trace, pottery vies with primitive weapons for the most distinctive place. Among the ancient cave-dwellers of central France, the lake-dwellers of Switzerland, and the cliff-dwellers of the western United States, earthenware was clearly in common use. Wherever excavations have uncovered the domestic haunts of these dispossessed races, as well as their burial mounds or stone-sheltered graves, it has been seen that pottery of two kinds was produced, — rough vessels for daily needs, and more hardened wares designed for ceremonial purposes. Art was introduced, perhaps to honor the dead, perhaps to propitiate whatsoever spirits were supposed to have the dead in their company. The sides, and often the bottom, of the sacred urns were ringed round with ornamental bands marked in the clay; and between the bands designs were drawn in short, straight lines, inclining towards each other at varying angles. The strength of the artistic instinct of man in his most primitive state is remarkable. Whether ruling lines in wet clay by the use of an indenting string or fiber, or drawing the outlines of the animal he was hunting, on the handles or blades of the weapons which he was using, he seems to have felt the need for ornament. Artistry was a twin birth with utility; and today the use of clay in manufactures is divided between the convenient and the beautiful.

That the making of pottery should be the oldest of all domestic manufactures is so natural as to be inevitable, everywhere. In its simplest form earthenware needs no tools. The human hand suffices. The wildest man who runs the woods must feel the need of some contrivance in which he can store his beverage. He sees that the clayey soil holds the water where he stickily paddles, and that the clay is molded by his feet. He sees that when the sun has dried up the water it hardens the clay, which again is softened by the wet. What, then, can be simpler than to scoop up the soft clay, knead it and mold it, and set it to dry and harden in the sun, into a reservoir for slaking thirst, or a jar-shaped storage place for food that the animal thief cannot readily rob? The smallest child can mold clay, and likes to do it.

When the use of fire became common, the quickening of the sun's burning and the greater hardness of fire-baked pottery would be suggested immediately, and the hand-shaped clay vessel, carefully baked, would soon become an object of pride. So simple is the process that among the least inventive races it has been independently evolved everywhere, and the rapid improvement of pottery has proceeded spontaneously in all parts of the world where the people have reached a fair average of intelligence. Indeed, the great difficulty in tracing the rise of the pottery manufacture on a world-wide scale arises from the fact that in every direction there have been spontaneous and independent invention and improvement. It is the one example of a universal manufacture without great need for borrowed ideas.

The wonderful wheel that was invented again and again

Pottery of some kind may be made everywhere. What kind it shall be will depend upon the ingenuity of the people of each locality, and the quality of the clay that is available. Before there was much interchange of commodities between distant nations, especially of such perishable goods as earthenware, every considerable community that had in it sufficient intellectual vitality to build up a distinctive state had evolved its special style of pottery, and in many instances had advanced it to a high state of perfection. Not only use but beauty had been attained. Under such circumstances it is absurd to talk of priority in manufacture. That simple mechanism the potter's wheel, which came early to the assistance of human hands, arrived as a matter of course in many places. It was independently invented, no doubt, again and again. The Greeks claimed it as their discovery. But it was known to the Egyptians and the Chinese long before the Greeks had emerged as a conspicuous or individualized people. Various mythologies tell of its bestowal as a gift from the gods. The gods that gave it birth were Necessity and Invention; and it came as soon as it was wanted, alike in Egypt, in Chaldea, in China and in Peru, an instance of that reaching-forward, inherent in mankind, that, judged broadly by its results, is named Progress, and is the sign-manual of the Divine.

Kinds of pottery that merge into each other where they meet

Pottery may be divided into earthenware, stoneware and porcelain. The earthenware is porous after firing, and may range from the common flower-pot or terracotta vase to white china. Stoneware is fired at a higher heat than common red earthenware, has a hard, vitrified body, and may be decorated with a glaze. Porcelain, made of soft or hard paste; the latter, being true porcelain, is white, vitrified and translucent. White earthenware and porcelain call for the highest grades of clay.

Glancing broadly over the various forms of earthenware and porcelain of the past and present, one must see that by whatever name each may be called, or whatever its place of origin, six considerations have determined its quality First, there is the choice of the clay, or of the materials that are mixed with the clay to give it the characteristics that are needed Primitive pottery depends for its color and consistency almost entirely on the nature of the clay of its particular locality.

The supremacy of China for porcelain was established originally by the possession of clays of extraordinary purity, and their manipulation with great skill by a minute subdivision of labor. The letters from China of the Jesuit missionary Father d'Entrecolles, which first described in detail for Europeans the methods of Chinese manufacturers, at the beginning of the eighteenth century, point out that the best chinaware can only be made in certain places, and that attempts to attract the workmen elsewhere have led to non-success in their work. But today the workman no longer goes to the clay, unless he is making low-grade wares; the location of the plant is determined by so many other considerations that the clay is brought to him Next comes the working of the clay, so as to give it in composition and consistency the right qualities. This is still done, in principle, by the same methods that were in force two thousand years ago. Father d'Entrecolles tells how in the case of the finer grades of Chinese porcelain a hair or a grain of sand left in the paste may ruin the whole work.

Then follow the designing and shaping of the article concerned. Vessels graceful in outline were built up by primitive man before the invention of the potter's wheel. Thus the early Indians prepared their clay in long strings, and coiled these up to make the jar, welding them together by pressure, and smoothing or decorating the exterior with rough tools. In all lands and times there has been, of course, a disposition to repeat conventional designs, with the result that any single work of the potter's art has been produced by many minds and hands.

KAOLIN BEDS IN THE SOUTH

KAOLIN MINE AT PENLAND, N. C., SHOWING FELDSPAR MINES AT LOWER LEVEL

Photos Southern Railway Co

NEAR VIEW OF FIFTEEN FEET OF PLASTIC KAOLIN AFTER STRIPPING, LANGLEY, S. C.

D'Entrecolles mentions that in the best center for manufacture of Chinese porcelain, during the palmiest days of that world-wide trade, as many as seventy workmen were employed successively on one piece, and often it was built up in parts. One result was a failure to create new designs. No one could model and carry through new work as a whole; and when porcelain became a present for kings, and the emperor of China sent an order for wares that would express ideas of his own, the carrying out of these ideas was found impossible, and the native Christian pottery workers asked the Jesuit Father to use his growing influence in petitioning that the order should be withdrawn, and no more workers be bastinadoed for failing to accomplish the impossible.

Work so delicate that the slightest mistake in making will spoil it

The next feature common to all ceramic art is the baking, or firing, of the wares. This is often done three or four times over, as will be explained later; and the danger of it in the case of delicate fabrications, like the choicest examples of porcelain, accounts to some extent for the expensiveness of the articles finally produced. Everything may look promising, but when the kiln is opened, failure is likely to stare one in the face unless all previous steps have been properly carried out. Slight deviations in the compounding of the clay mixture, too high or too low temperature in the kiln, too rapid heating or cooling may all be responsible for ruining much or all of the kiln contents. Indeed, it has taken many years of experimenting, and many dollars spent, to learn the secrets of modern ceramic art, whose products, rendered ineffaceable by their baptism of fire, are the admiration of all.

Between the firings comes the process of glazing or enameling, rendering the surface smooth and non-porous. The use of glazes has been known from early days, as is seen in Egyptian pottery, their alkaline glazes, however, proving very uncertain. Lead glazes are most general for ordinary earthenware, feldspathic glazes for hard-fire porcelain, and salt glaze for stoneware. Glazes are put on sometimes over, and sometimes under, coloring and patterns. Pottery that remains as it was before the glazing stage is called "biscuit". After the glaze is put on, another burning takes place.

Where the Oriental sense of color outmatches our Western mechanical art

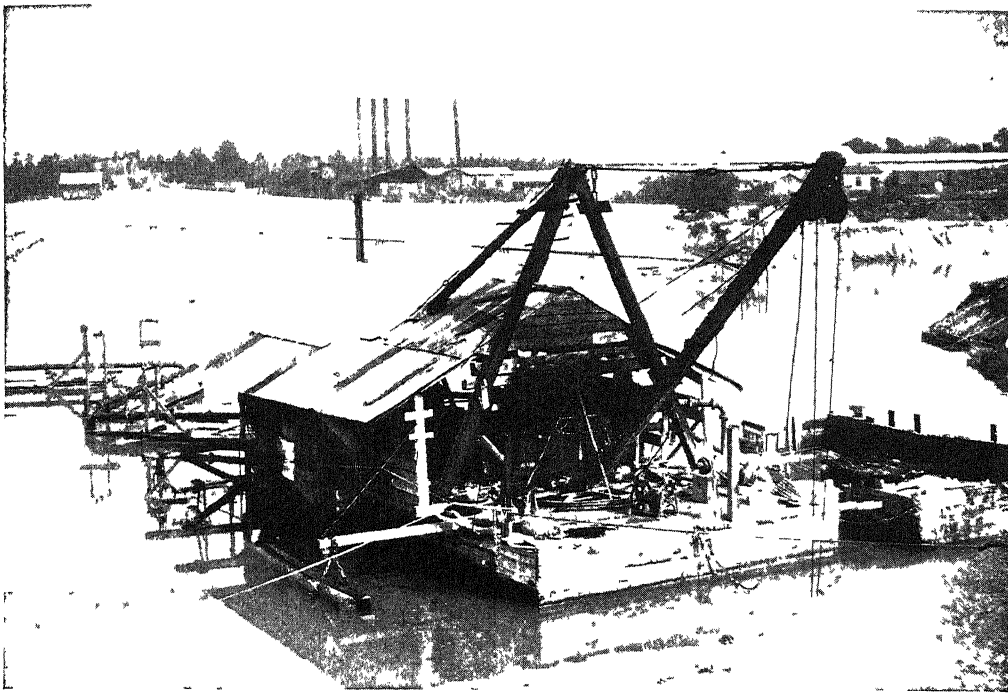
The coloring and painting of pottery is the last stage through which it passes; and color as much as texture has given certain types of work an artistic value that has been recognized in all parts of the world. Pottery was originally colored by the coloring matter of the clays used. It is now decorated by painting, transfer printing, or even color effects in the glaze, the last sometimes yielding a wonderful depth and brilliance of tone.

From the sun-baked pottery of primeval man to the gorgeous art treasures of the most delicate porcelain is a long story, and telling of it at length would introduce almost every nation, ancient and modern. The earliest pottery of which we have specimens is undoubtedly Egyptian, for though China claims extreme antiquity for her industry, her proofs are unsatisfactory, and her samples non-existent. She came to the front as the producer of the world's most delicate earthenware rather more than seven centuries ago, when a present of Chinese wares from the Emperor Saladin to the emperor of Damascus made a noise throughout the world by its astonishing beauty. Nearly 3000 years before that, Egypt was producing pottery of a type that has been claimed as porcelain.

World-wide exchanges in ancient days of delicate products of taste

At the same period, and later, the Mesopotamian empires were using baked earthenware in many ways; and today the moldered remains of their clay-built cities cover their clay-written libraries. The Phœnicians had a certain rude expertness in earthenware, and undoubtedly used it freely for domestic purposes. Greek pottery had all the Greek taste in beauty of form and refinement in ornamen-

DREDGING AND DRYING THE KAOLIN



DREDGING BALL CLAY AT EDGAR, FLORIDA

In the background is seen the washing plant where the sand is washed out of the clay. The large sloping pile at the left is the refuse sand.

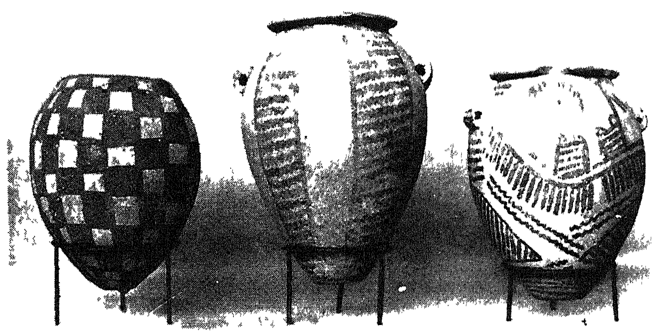
Photo Southern Railway Co

KAOLIN DRYING IN SHEDS AFTER WASHING, LANGLEY, S. C.

tation. When the Chinese sold their wares by sea to the Saracens, they were trading with the men best able to appreciate their skill, for, probably by transmission from the Persians — adepts in the art — the Mohammedan power itself was coming to be regarded in the West as pioneering Eastern architecture and the gorgeousness of Eastern ceramics. The Arabs and Moors knew the use of tin and lead for glazing, but these ingredients were not abundant in the East. But when the Moors conquered Spain in the twelfth century, they found the necessary tin and lead, which enabled them to develop their famous enameled ware known as Majolica.

It was the Italian artists of the Renaissance, however, who brought enameled wares to their perfection, and the works of Luca della Robbia, Giorgio Andreoli and others are unique as well as attractive.

After Italy had developed the manufacture of enameled ware, with its thin glaze or enamel, the art passed with Catherine de Medici into France, where Palissy was conducting his experiments, and eventually the making of soft-paste porcelain became identified with Rouen, St. Cloud and Sèvres. Hard-paste porcelain was first established in Europe at Meissen, near Dresden, by Johann Friedrich Böttger, who probably was put on the track of the right materials by the agents of the Elector of Saxony, engaged in bringing together his rare collection of Oriental porcelain. Within a dozen years of Böttger's early death, Meissen porcelain was supplanting that of China in the Near East. Dresden still retains its preëminence.



Courtesy The Metropolitan Museum of Art

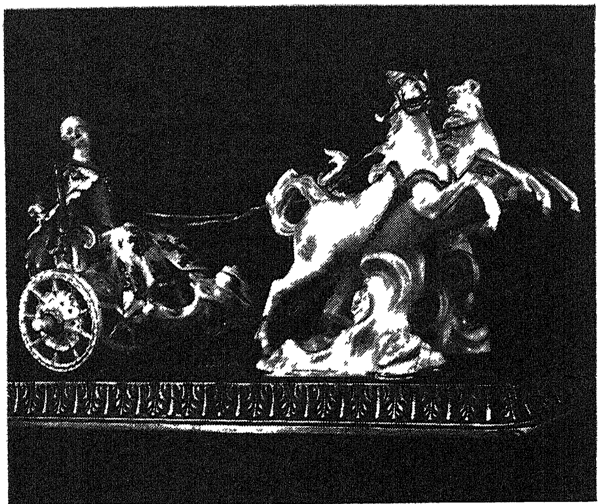
EARLY POTTERY

Earthenware vases or jars of the Egyptian Predynastic Period, about 5000 B C.

British works of a distinctive character were established at Chelsea, Bow, Derby, Worcester, etc. But on the continent of Europe, too, there had been a great development of porcelain for both utilitarian and decorative purposes, the latter especially having won fame for the factories at Copenhagen, Sèvres and Berlin.

On the human side there emerge, from this growth of the ceramic art, here but scantily outlined, three great personalities, Bernard Palissy, Johann Böttger and Josiah Wedgwood. Palissy, the son of a poor worker in glass, was born about 1509, to the southeast of Bordeaux. Having learned the trade of glass-painting as a youth, he wandered in the practice of his business, which he varied with portrait-painting and land surveying, over France, the Low Countries, and part of Germany, till, when nearing thirty years of age, he married and settled at Saintes, to the north of Bordeaux. At that time the manufacture of earthenware in France remained in quite a rude stage; and when an enameled cup of Italian make came into Palissy's hands it was a revelation, and he determined to devote himself to the discovery of a glaze that would enable him to pursue the career of an art potter, though he knew nothing of the ingredients of such wares, nor of the process of baking them.

Fired by an ambition which became a passion, he began experiments that were continued for sixteen years through almost incredible difficulties. He pounded all kinds of substances in the hope of finding the constituents of an enamel, broke up



Metropolitan Museum of Art

Dresden porcelain, of which this is an eighteenth-century example, was first produced at Meissen, Germany, by Böttger.

earthen pots by the hundred and baked them afresh with his pounded substances and chemicals in a furnace of his own making. Unfortunately his many experiments yielded unsatisfactory results, and he had exhausted his money on earthenware and fuel.

In tile furnaces and glass furnaces he continued to experiment with his broken pots and chemicals whenever he had earned a little money by land surveying. At last, after years of effort and failure, he secured a single specimen of white enamel. He then built a furnace, baked some vessels he had fashioned and covered them with his enamel compound for a second baking. But the enamel would not melt. For six days and nights he fed the fire. Not only did the enamel fail to melt, but his pots were now spoiled. With borrowed money he bought more fuel and pots, covered them with his favorite compound and relighted the furnace; but the fuel disappeared and the enamel had not melted. The garden palings, household furniture and shelving from the walls were thrust into the furnace to raise the heat; and then while his wife rushed through the town crying that her husband was mad, the enamel melted, coating the rought pots with a beautiful white glaze. Palissy's long search had at last been rewarded.

What Palissy suffered during these years from his uncontrollable materials was scarcely less disheartening than the reproaches of his wife. Indeed, after the discovery of the enamel, some eight more years were spent in experiments before the potter's perfected discoveries could take the form of salable wares. Then the ornamental crockery for which he was both artist and craftsman began to be popular, and Palissy became "inventor of rustic figulines [figurines]" to the King. About 1562 he moved to Paris and set up his pottery works near the Tuileries. Though a Huguenot, he was protected by Catherine de Médicis. He worked in Paris for more than twenty years, becoming a philosopher, a writer and a scientific reformer. His best-known productions are his *pièces rustiques* — dishes decorated with crabs, frogs, snakes, shells, lizards and plants in their natural colors. His plates with mythological figures for their subjects are even more highly valued, however. The J. P. Morgan collection includes fine specimens of his work, which is also well represented in various European museums, especially the Louvre.

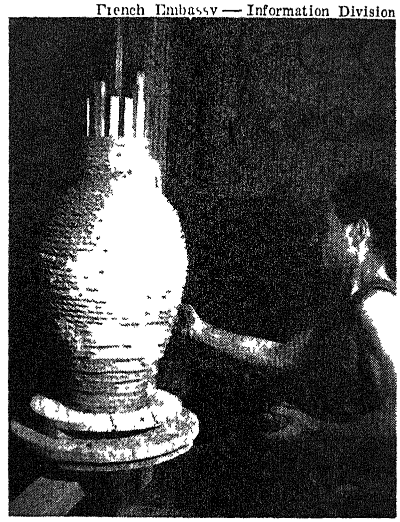
John Böttger was cast in a ruder mold and had a strain of the charlatan in him, but his story is as romantic as Palissy's, notwithstanding its discordant tone. He was born at Schleiz, in Thuringia, in 1685, and apprenticed to a Berlin apothecary, in whose laboratory he claimed to have made gold. When Frederick I wished to replenish his purse from the young alchemist's "gold," the lad fled, with a regiment at his heels, and took refuge in Saxony, where the Elector protected him. Again he was in danger because he failed to make gold for the Elector, but eventually he was put to work in the laboratory of Pschirnhaus, the chief chemist at the Dresden court. Here he succeeded in making a kind of red stoneware, capable of a high polish, and resembling porcelain in texture, but not in transparency.

THREE METHODS OF SHAPING POTTERY

Using the pottery wheel in Norway today. As the whirling disc rapidly spins the clay, the potter's able hands, working with inside and outside pressure, create a piece of ceramic art.

Norwegian Official Photo

French Embassy — Information Division



A skilled French artisan, using a method handed down for generations, shapes a vase.

Museum of the American Indian

A Zuñi Indian fashions pottery by an ancient method. Strips of clay are rolled out, and one coil is placed upon the other. The hollow pot takes shape by a careful working of the coils with the fingers.

At last he discovered the secret of a white porcelain, it is said, by using the powder on his wig as an ingredient in his experiments. Bottger's success was his undoing. He was guarded day and night to prevent his escape with the secrets of his search, and the Elector established a royal manufactory for exploiting his skill. Here Bottger was kept a prisoner and treated as a slave; under this cruel treatment he became a drunkard and died in his thirty-fifth year. The workmen in the factory, running away to avoid his fate, carried the secrets of the business with them, and so the making of porcelain spread through the royal factories of Europe.

Josiah Wedgwood, a master of the potter's art

Josiah Wedgwood began work as a potter at the age of ten. He was born at Burslem, in Staffordshire, in 1730, the son and grandson of a potter. Beginning with the study of chemistry, he observed closely the properties of different kinds of clays and earths. He made experiments with fluxes and glazes, till after numerous failures and heavy losses he produced earthenware and porcelain that spread the fame of English pottery throughout the world. Wedgwood knew the charm of classical art, valued form as well as texture and ornament and called to his assistance the best designers. The work done by this broad-minded and capable man is well summarized in his epitaph He "converted a rude, inconsiderable manufacture into an elegant art and an important branch of national commerce." He became the most renowned potter in Europe and was so influential that, impatient with the slow transportation of his increasing volume of orders, he instigated the construction of better roads and the development of canals throughout England.

Types of pottery and clays used in their manufacture

The methods of making pottery are in general much the same the world over but differ somewhat with different kinds of ware. Common red earthenware calls for a single clay, and so may gray stoneware, but both white earthenware and porcelain are made of mixtures of kaolin, ball clay, ground flint and ground feldspar. The exact proportions used are always a carefully guarded secret, which is often handed down from father to son.

For common earthenware and stoneware the clay is simply kneaded thoroughly before molding, but for white wares the ingredients (some of them previously refined by washing) are mixed with water to a creamy liquid, or slip. The slip is then forced through a filter press, and the doughlike mass of clay is removed for shaping by the potter.

Ever since the days of the ancient Egyptians, the potter has been known to form his wares on a wheel — a process requiring such skill and dexterity as to command the greatest admiration.

The potter's wheel aids in shaping pottery

The potter's wheel, or throwing machine, is a vertical shaft supporting a revolving horizontal disc upon which the clay is molded, either by hand or by tools, as it is whirled around. There is no more striking process in all the operations of manufacture than this ancient one of raising graceful shapes by the action of the hand, the eye and the flying wheel. The shaped vessel is then put aside to dry. When it is tough enough to be handled, it is placed on a turning wheel and more exactly shaped, trimmed and smoothed. Many articles, particularly of the finer and more ornamental kind, are cast in plaster-of-Paris molds, into which the liquid clay, or slip, is poured. Parts, such as handles and feet, are very often cast in separate molds.

The potter forms other articles partly by molds and partly on the wheel, or he uses molds for the outside and shapes the inside by hand or by tools. An innovation of the latter process is carried out on a jigging machine. This machine makes possible mass production of similar pieces. Regardless of technique, the working of pottery, so far described, has had the dramatic quality of swift and visible formation.

The next stage is slow, delicate and momentous. After drying, the article is fired in the biscuit (bisque) oven, and after this initial firing it is called bisque ware Each article is placed so as not to touch another in a sagger, or clay box, which protects the ware from direct contact with the flame. The number of articles in each sagger varies according to their size, shape and importance The saggers are piled on each other in a kiln, and spaces are left between each pile, or bung, of saggers to allow for heat circulation.

The simplest kiln, or oven, is such that it requires the stacking of ware in saggers, firing and then cooling for a period before it can be emptied. The advent of mass production prompted the construction of various types of kilns that could be maintained constantly at high temperatures and that would allow for the articles being fired to be brought gradually into the area of highest heat and then as gradually removed from this area Whether the kilns are for bisque ware, glazing or decorating determines the size and control of the fire Firing time may vary from a few hours to several days

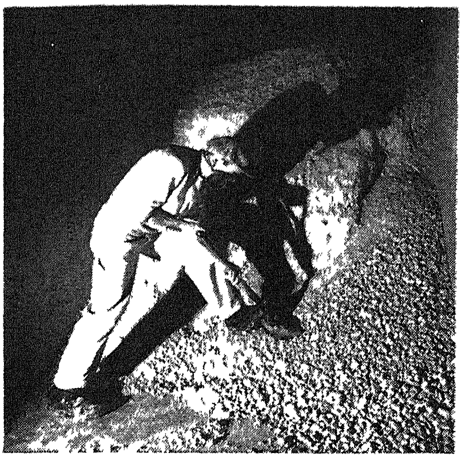
In some cases the bisque stage completes the ware or, as with some stoneware, the pieces are set unprotected in the kiln and glazed by throwing salt into the fire boxes The volatilized salt, mixing with the silica in the surface paste, forms an even glaze over the whole article. Though of infinite variety, glazes essentially are layers of molten glass fused by firing to the clay's surface A single baking suffices for sanitary tilings and stoneware jars, but more elaborate or ornamental vessels need repeated treatments.

Often a printed pattern is applied to pottery at the bisque stage Transfer paper is used from which the porous bisque ware

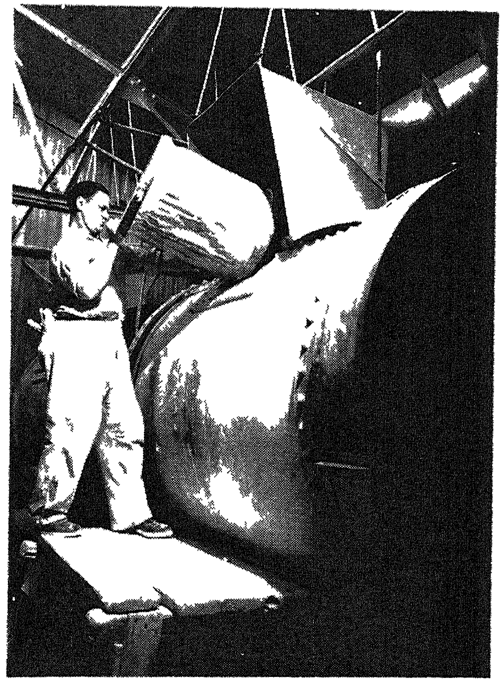
Lenox Inc

From the artist's design, the sculptor skillfully shapes in plaster of Paris or clay the master model.

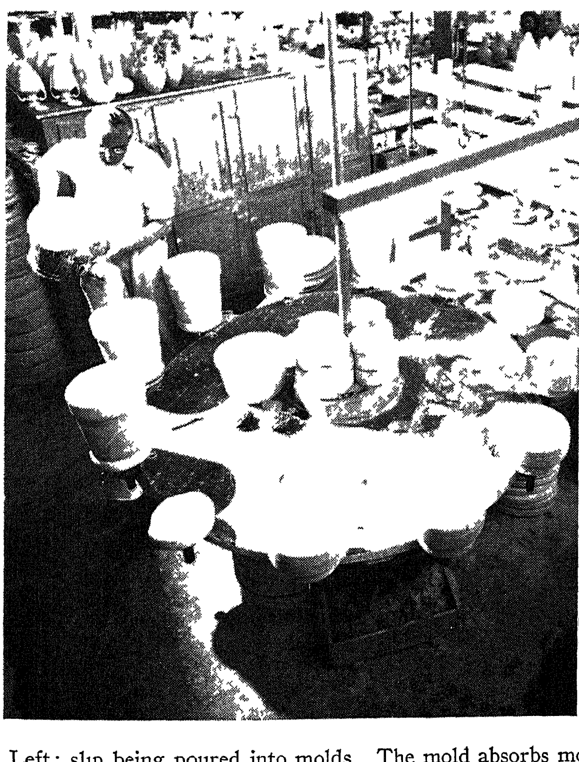
FROM RAW CLAY TO CAST POTTERY

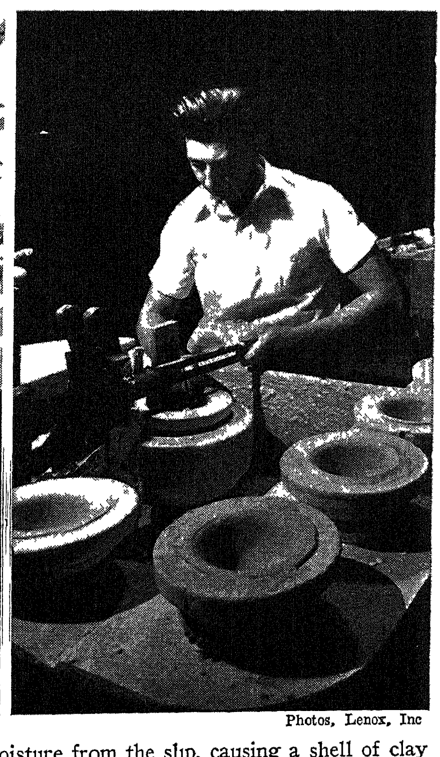


The clean, dried and partially refined clay is removed from the storage bin so that it may be weighed, ground and mixed



The mixing cylinder grinds the raw clay and other ingredients to face-powder fineness Water added to this forms slip



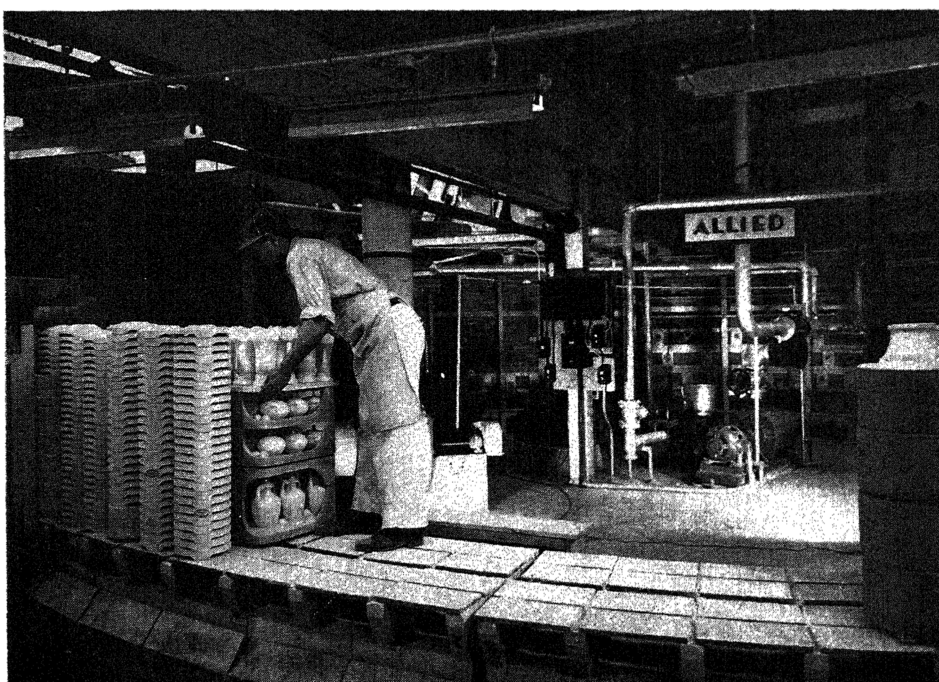


Photos, Lenox, Inc

Left · slip being poured into molds The mold absorbs moisture from the slip, causing a shell of clay to adhere to the mold. Right. inside of a cup being jiggered (shaped) by a tool called a profile.

STEPS BETWEEN MOLD AND KILN

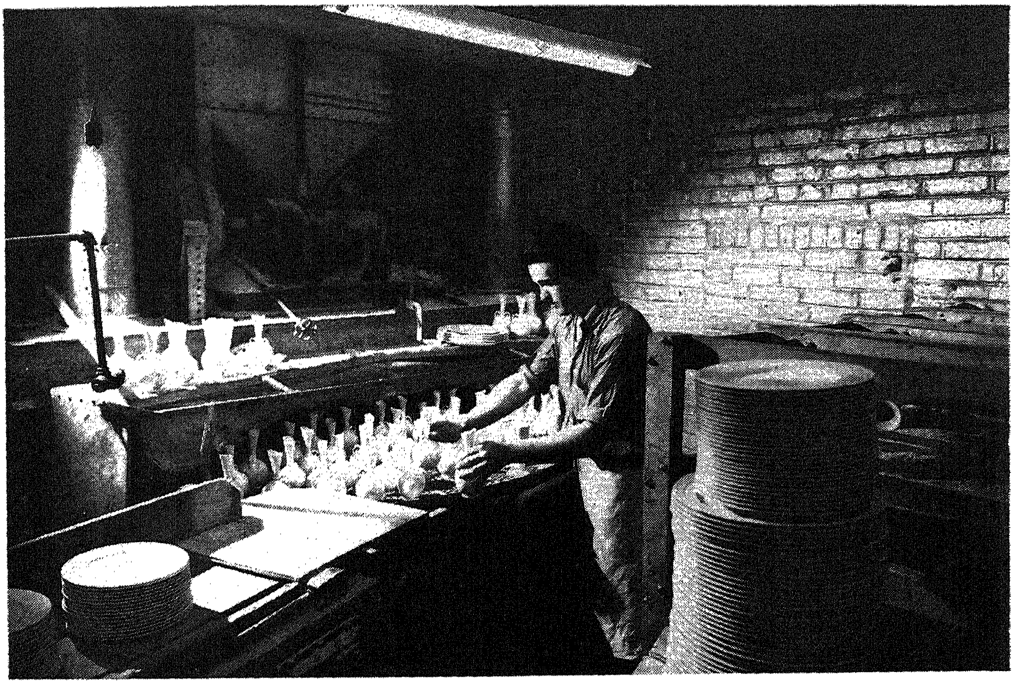
Finishing cast ware by removing mold seams and other irregularities caused by the casting process.



Photos, Lenox, Inc.

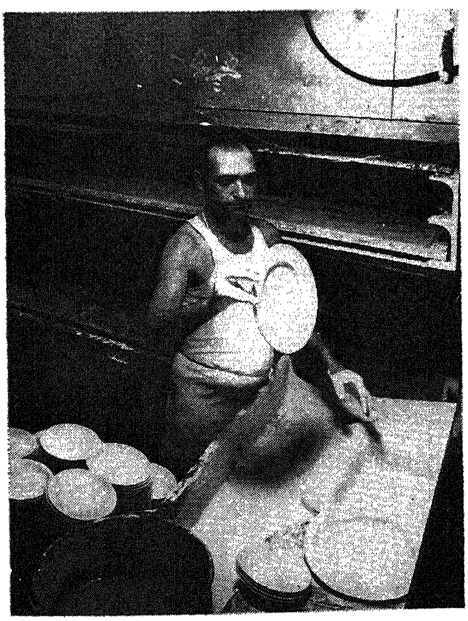
The fragile, chalklike cast ware going into the bisque kiln will come out vitreous and translucent.

THE FINISHED PRODUCT APPEARS

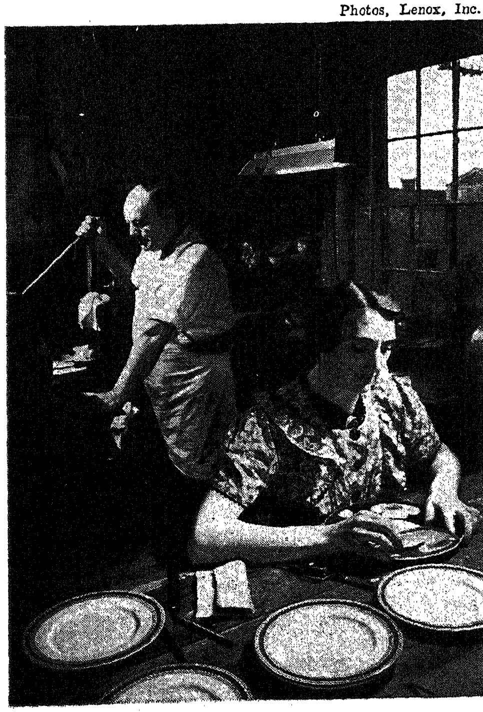


Ware after its first firing (bisque ware) is cleaned, or scoured, by sandblasting.

Photos, Lenox, Inc.



The ware is dipped into the glazing compound (liquid glass), after which it is again fired.



Gold-leaf designs are carefully transferred from specially prepared tissue paper to the chinaware.

absorbs the ink. The ware is placed in a low-heat kiln to fasten the colors and then dipped into a glaze composition, after which it is placed in the glost, or glaze, oven and fired a second time to harden the glazed surface. Care is exercised in dipping the ware evenly and in preventing any article from touching another in the glost oven. If the glazing is successful, the pattern underneath the glaze comes out clearly. Ordinary ware, with or without a pattern, is completed at this stage, after being fired at a lower temperature, more gradually and for a shorter length of time than in the bisque process.

Further stages involve decorating the ware over the glaze. The colors and decorations are printed or painted on the glazed surface, and a third firing is given, in the enamel kiln, at a still lower heat. The article increases rapidly in value through the work that is being done upon it, as well as the growing delicacy of its finish.

The marvelous range of the potter's craft is one of its most striking characteristics. It begins with a stone ink bottle and ends with works of art that are priceless. There is considerable doubt as to the value of many examples existing over this vast range, since antiquity is always being copied and counterfeited.

The art of pottery lends itself in a remarkable degree to imitations; and in that respect English potters have been particularly successful. In Wedgwood's day, the excavations of Pompeii were calling attention to the beauty of classical forms, and the great potter not only produced vases in the classical spirit, but copied with exactness the works of antiquity. The celebrated Barberini (now known as the Portland) vase, found near Rome, was lent him by the Duke of Portland, and fifty copies of it were made with a wonderful fidelity. Wedgwood regarded this reproduction as his masterpiece.

Syracuse China

Hand painting by an expert. Science, craftsmanship, artistry together create a piece of lasting beauty.

The important discovery of the China clay deposits in Cornwall

The best grades of pottery have to be made of the whitest clay, or kaolin, a substance that was known to the Chinese long ago, but when the oriental china was first brought to Europe potters could not at once imitate it, as they lacked the necessary raw materials, which even at the present day have not been discovered in inexhaustible quantities. The largest deposits known are those discovered in Cornwall by William Cookworthy, a Quaker apothecary who set himself to find the best English earth for porcelain-making, after reading Father d'Entrecolles' letters about the Chinese industry. After twenty years of experiments he began the manufacture of hard porcelain, and to this day the Cornwall kaolin is employed not only for this purpose, but also in other grades of whiteware. Indeed, the pits supply factories in Europe, Canada and the United States But the search for this purest and whitest kind of clay has continued, so that deposits have been found in other European countries as well as in several parts of the United States. In all cases the china clay must be washed to free it from the sand and mica that it contains, since only the finest and whitest particles can enter the ware. To further help out, the potter must also add a more plastic white clay, known as "ball clay", in order to give the mixture the plasticity necessary to permit its being molded into the various delicate and complex shapes which can be fashioned by hand and machinery.

How the potter's industry has helped the sanitary reformer

From the earliest times the products of the potter's art have been of two distinct kinds — they have ministered to men's convenience in practical ways, or to his sentiment and taste. It is the same today, with great developments in each direction, but chiefly in that of utility. The ancient usefulness of the potter's wares took almost exclusively the form of storage. Liquids or food were kept safe in the family jars. That usefulness has been greatly extended in modern times. The glazed drain-pipe, for example, is the stand-by of the health reformer. The potter, indeed, has taken possession with increasing confidence wherever disease may find a lurking-place. In all sanitary fixtures, in the walls of bathrooms and kitchens, wherever absolute cleanliness is imperative, porcelain is now the universal requisite.

Then the range of earthenware vessels in ordinary use has been vastly extended The number of "pieces" on the shelves of a modest house counts into hundreds The common number for a full dinner-service is six dozen. There are bedroom-sets and breakfast-sets, and coffee-sets, and afternoon tea-sets, and dressing-table sets, with new accessories and designs tempting the tasteful. In cookery, too, fire-resisting crockery has won new ground.

The objects of art that enter both cottage and palace

Along the whole range of utility that borders on taste, and promotes the amenities of life, the art of the potter is more frequently requisitioned. No feature of our modern life tells the story of its advance in comfort more clearly than the growth of such great pottery centers as Trenton, New Jersey, and East Liverpool, Ohio

Whether equal advance has been made in the region of pure taste and artistry may be questioned. It is true that the potter has turned his back on the appalling monstrosities that were once thought to be decorations, and a true conception of harmony in color and grace in form is prevalent, but it may be doubted if anywhere in the world the art of the potter is excelling in delicacy and charm the productions of five hundred, a thousand, two thousand years ago. We have several times produced here pottery worth over $45,000,000 annually, but if we desire fineness in conception or choiceness in workmanship we make our first search in the past. No doubt today there is more artistry at less cost, but not finer artistry at any cost, for it may be doubted whether man's taste has developed commensurately with his commercial and intellectual progress.

Hill peat dominated by Scotch Ling (*Calluna vulgaris*), Pennine Range, England.

Hill peat, showing denudation by wind and rain forming drainage channels, Pennine Range, England.

PEAT BOGS

What they are, where they are, what grows in them and what they reveal

THEIR VEGETATION AND HISTORY

THE study of the distribution and history of vegetation over the surface of the earth brings before us a drama of slow but widespread changes stretching back into the mists of the past. This is especially the case with regard to the vegetation covering peat bogs in the northern temperate zone of the world. Peat is composed of the partly decomposed remains of vegetation which often collects to a considerable depth, but in spite of partial decomposition the remains of the plants from which the peat has been formed are frequently recognizable These deposits of peat, covered with an interesting assemblage of plants, are found in extensive regions in northwest Europe, the British Isles and central and northern North America. Just as a glacier represents an accumulation of snow in excess of summer melting, the peat represents an accumulation of plant remains in excess of decomposition by the agency of fungi and bacteria Such deposits only occur in certain topographical situations and under certain climatic conditions They frequently occur in old lake basins and among the morainic deposits of the last glacial stage and on hillsides in climatic conditions favoring excessive rainfall, a high humidity and a fairly low temperature. The plant remains in the peat and the vegetation covering it at the present time have been a subject of detailed study by botanists, and we are thus enabled to reconstruct the history of the various types of vegetation as it immigrated during the shrinking of the ice-sheet, its subsequent history and the changes which are occurring at the present time. Notwithstanding several important differences in its constitution, there is a general similarity of aspect in the vegetation covering peat areas in Europe and America. In northwest Europe the peat is usually covered with members of the Ericaceæ, prominent among them being the Scotch Ling (*Calluna vulgaris*). At other stages of development the most prominent plants may be the bog moss (*Sphagnum*), small sedges, particularly *Scirpus Cæspitosus*, and the cotton grass (*Eriophorum*). In such regions trees are absent, and the type of vegetation forms what are popularly called "moorlands." Most typical representatives are found over large areas in Scotland, northern England, northern Germany, Denmark and in some parts of Scandinavia and Russia An example of Calluna moor on the Pennine Range in northern England is shown in the upper illustration on page facing.

In America also, peat areas are covered with a vegetation in which members of the Ericaceæ are prominent, the most typical plant being the Labrador Tea (*Ledum palustre*). At an earlier stage of development the same plants may be present as in Europe,—such as bog moss, sedges, and cotton grass. At a later stage, trees become a salient feature, the most widely spread being the black spruce (*Picea mariana*).

Investigation of a large number of bogs in different countries leads us to the certain conclusion that the vegetation covering peat areas passes through a definite series of changes during long periods of time.

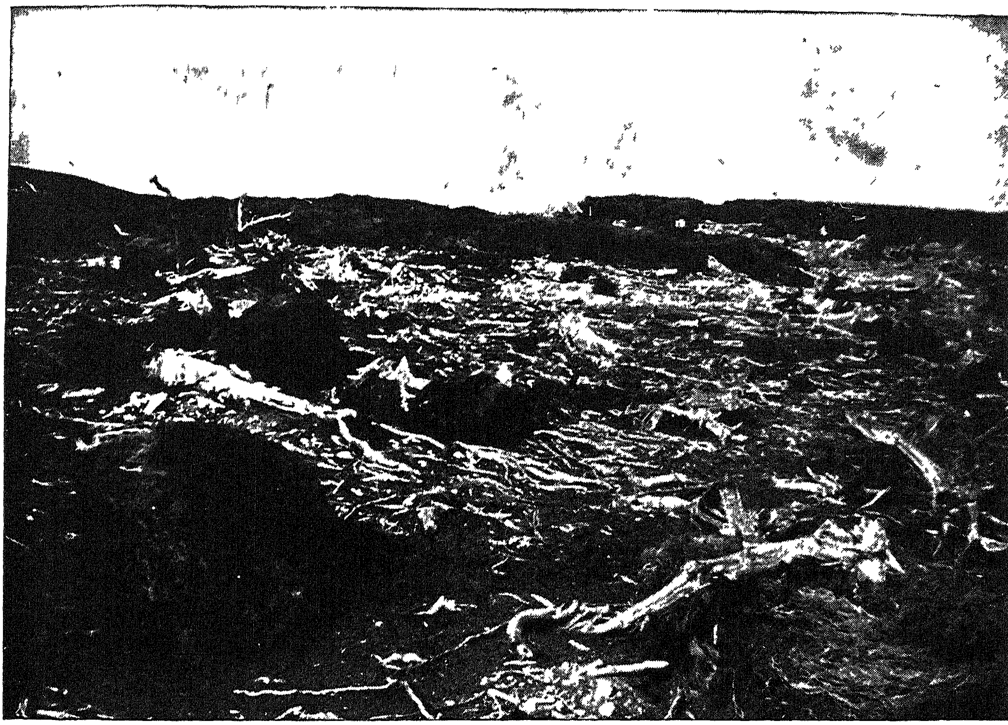
Throughout the north temperate regions two types of peat bogs may be recognized according to the topographical positions in which they occur. In northwest Europe and also in the British Isles and North America, peat bogs are frequently developed in basins which in earlier post-glacial times were occupied by lakes. In the course of ages these lakes have been filled with vegetable material and have been successively occupied by a series of very diverse vegetation. These basins very frequently occur, particularly in North America, between morainic ridges laid down by the last ice-sheet, and were originally probably filled with water containing colloidal clay material, derived from the ice lobes surrounding these areas. The history of these old lake basins can be fully reconstructed from an examination of the clays which form their floors and the overlying layers of peat formed of the vegetable remains which have grown during successive ages

In northwest Europe the bottom of these lake basins is formed of fine clay laid down during the waning of the ice-sheet. The upper surfaces of these clays frequently contain the remains of plants whose distribution at the present time lies well within the Arctic Circle. In the overlying peat the remains of forest zones are frequently recognizable and represent the somewhat drier and milder periods when forests had a much more extensive distribution in northwest Europe. These forest zones can be traced in Scandinavia farther north than some species of trees occur at the present time, and in the British Isles they occur at a higher elevation than trees are found today.

At present there are no trees on the more exposed coasts of northwest Europe, such as the Shetland Islands and the northern part of Scotland, but it is a remarkable fact that, in the peat bogs of these regions, the forest zones stretch outward to the very margin of the sea, in places where, owing to the succession of Atlantic gales, even the smallest shrub finds difficulty in existing. These facts strongly suggest that climatic conditions have varied considerably during successive periods.

The actual time which has elapsed since the last ice-sheet in Europe is now approximately known from examination of the glacial clays in Scandinavia The successive zones, due to annual melting of the ice, have been counted and traced from the south of Sweden to the far north; they give an approximate estimate of about 12,000 years since the last ice-sheet occupied the south Baltic region This brings the close of the glacial period into early historical times, when the first phases of the great Babylonian and Assyrian civilizations were just beginning

In North America something of the same state of affairs can be recognized in the peat bogs lying in lake basins In the northwest of Canada, in the provinces of Saskatchewan and Alberta, morainic regions are scattered all over the country, indicating places where the ice-sheet or lobes of ice halted for long periods. These complicated and extensive regions of moraines enclose basins of various size, some of them only a few hundred yards, others often several miles in diameter These features are especially well seen in the drainage areas of the northern Saskatchewan, Athabasca and other rivers which flow eastward from the Canadian Rocky Mountains. The basins are nearly always filled with peat averaging from eight to twenty feet in thickness. Their floors are peculiar in their uniformity, consisting, as they do, of extremely stiff, tenacious blue clay, representing the finer colloidal clays released by the slow melting of great masses of glacier remains. These clays have been found to contain in their upper layers a remarkable assemblage of plants, such as fragments of the bog moss, the bog cranberry and fungi which are characteristic of the surface of the modern peat bogs These remains may possibly indicate material from peat bogs which existed in the country before the advent of the last ice-sheet, caught up in fragments by the ice, possibly enclosed in it for ages, only being released when the ice melted and gently deposited the plant material among the finer clay. So far no Arctic plants have been found in these clays similar to those found in Scandinavia and elsewhere. If the last



Buried forest of pine trees exposed by denudation on the summits of the Cairngorm Mountains, Scotland, 2,700 feet above sea-level.

Low moor of grass-like plants. Early stage of peat bog development.

ice-sheet of North America was contemporaneous with that of Europe, the actual conditions of melting and immigration of vegetation pursued very different courses in the two continents. Unlike many of the European deposits lying in old lake basins, no definite forest zones in peat have yet been discovered in northwest America From the clay at the base of the peat to the top there are abundant remains of trees which are commonly growing on the surface at the present time. Further investigation may show that the buried forests can be resolved into definite zones, but the ability to recognize these zones depends upon the cutting of sections through a considerable depth of peat This is by no means an easy task when the peat lies in basins, owing to the flooding which frequently occurs. In many of the European areas such sections are more easily made, owing to these areas being better drained

During the last few years considerable attention has been paid by Swedish botanists to the distribution of pollen grains in the peat. These minute objects are practically indestructible and retain their delicate markings and characteristic shape indefinitely, when contained in peat deposits. Borings are taken with a suitable instrument so that samples of peat can be obtained from definite and different depths from the surface. A very small amount of peat is then treated with hot caustic potash solution and placed in glycerine on a microscope slide which is divided into minute squares and the relative number of pollen grains counted. In this way the relative frequency number of pollen grains of characteristic trees from different depths of the peat can be ascertained, and thus a knowledge be gained of the frequency of these trees at successive periods. This method of investigation has given valuable results in Sweden, Scotland, Finland and Germany, but has not yet been carried out elsewhere.

The first to take up the question of stratification in peat with particular regard to Sweden was F. W. Areschong, who in 1866 maintained that the present vegetation of Scandinavia was made up of at least three elements of different periods of origin:

1. An Arctic vegetation which immigrated from the East during the latter part of the glacial period, and, from its origin, may be called the north Siberian flora;
2 A northeastern and eastern vegetation which came into Europe from Siberia after the glacial period but before the immigration of the beech forest;
3. A southeastern and southern vegetation which came in simultaneously with the beech, probably from the Caucasus and the country around the Caspian and Black Seas and partly from the countries around the Mediterranean.

This initial point of view has in later years been amplified, and we now know that the following stages in vegetation have taken place in Sweden during the ten or twelve thousand years since the ice receded. The earliest stages represented at the base of the peat consist of Arctic plants, the most characteristic being Dryas and dwarf willows, which now grow only at high levels in mountain ranges or within the Arctic Circle

As the ice cap withdrew and the climate became warmer, the land began to rise In the center and the south of Sweden this took place so rapidly that land again joined Sweden and Denmark. The Baltic thereby became a lake, its waters growing gradually fresher and containing freshwater animals By this upheaval of the land a broad connection was opened for the immigration of plants from the southeast and east of Norway. Birch was an early immigrant and with it came in many of the plants which are now characteristic of birch forests in various parts of the world.

After the birch the Scotch pine was the next forest tree to come in, together with a number of plants associated with pine forests. The climate gradually grows warmer, the inland ice disappears, and the oak tree, the hazel and other shrubs become abundant. It is a period which is characterized by a much milder climate than that of the present day, for the fossil remains of the hazel have been found far north of its present distribution. From this it has been calculated that the mean temperature of the summer months must have been about 2.5 degrees C. higher than it is now. It is interesting to note that the earliest remains of stone implements in Norway date from this warm period, which in the opinion of archæologists must be assumed to have been about 7,000 years

TWO STAGES OF HIGH MOOR DEVELOPMENT

Andromeda spreading in on bog moss. The earliest stage of high moor in northern Alberta.

A later stage of high moor development with the Arctic bramble (*Rubus Chamæmorus*) and cowberry (*Vaccinium Vitis-Idæa*) spreading and replacing Andromeda in northern Alberta.

ago. The Scandinavian Stone age lasted about 3,000 years, so that the Bronze age in Scandinavia began about 4,000 years ago, and it was not until the Bronze age that any noticeable fall in temperature seems to have taken place. During the Bronze age the fir immigrated to Norway from the east and became the dominant tree on and around peat bogs.

After the Norwegian fir, following the fall in temperature, the beech began to make very definite advances and spread over large areas in southern Sweden. It may be that this immigration was accelerated by the influence of man in the time of the Vikings. We see then that the post-glacial history of vegetation in Scandinavia has shown a constant succession of immigration, coinciding with comparatively slight, but well defined, changes in climate and land distribution. When such detailed studies have been made on the past vegetation of North America no doubt an equally interesting history will be written regarding the immigration of vegetation from Asia by Behring Strait and from Europe through Greenland and the islands to the north of Canada.

Leaving the peat deposits occurring in old lake basins, we can now turn our attention to the peat bogs on sloping ground in hill and mountain ranges. These are extremely well represented over great slopes in the southwest of Scotland and the north of England, where hilly ranges are covered with peat averaging from 5 to 15 feet in depth. This forms a thick mantle over the rock and over the boulder clay deposited by the last ice-sheet. Unlike the deposits in old lake basins, the surface of these peat bogs is deeply furrowed by channels formed by the rapid flow of water during the rainy periods. In many areas they form a veritable network on the hillsides, and have frequently been cut down to the base of the peat and into the underlying boulder clay, thus exposing excellent sections of the whole thickness of the former. This is well shown in the lower photograph on page 2946. One of the most noticeable features to be observed is the almost universal presence of the roots and trunks of trees of one or sometimes two buried forests, the lower containing the remains of birch, hazel and other species, and the upper the remains of Scotch pine and sometimes oak. It is frequently found that these buried forests are present in the peat at elevations far beyond the limit of present-day tree distribution. Thus on the summit of the Cairngorm Mountains in Forfarshire and Aberdeenshire, at an elevation of 2,700 feet, the upper buried forest has been entirely exposed, owing to the denudation caused by wind and rain. Trunks, roots and branches lie over the surface of the ground in the utmost confusion, and form, as can be seen in our illustration, a striking and suggestive spectacle on the summits of these grim and northern mountains. At the present time no trees grow on the flanks of these mountains at a greater elevation than 1,800 feet above sea-level, so that we have a clear demonstration of great climatic changes during the formation of the peat deposits. The exact correlation between these forests in northern Britain and those occupying certain horizons in the Swedish peat has not yet been definitely decided, but there can be no doubt that these forest beds, which occur at such unusual levels and which can be traced out to isolated islands in the Shetlands fully exposed to the fury of the Atlantic gales, really represent a very definite climatic stage favoring a spread of forests over the whole of northern Europe. In some cases the remains of Arctic plants have been found at the base of this peat of the same character as those occurring below the Swedish peat.

We can now consider the way in which these thicknesses of plant material originate, directing our attention first to those occurring in basins, such as those in morainic areas in central and northern Alberta. The main features of this type of development are so uniform, and the vegetation follows such a similar path of succession, that a general account of them can be given characteristic of all areas. The typical plants concerned are not numerous and we frequently find the same genera, but not always the same species, engaged in this process both in North America and in Europe.

The conditions during the earlier phases of peat formation favor a water supply rich in calcium, potassium and other mineral salts. Under these conditions grass-like plants, such as sedges and rushes, together with other flowering plants and shrubby species of willows, birches and alders, usually predominate. This forms a vegetation about four feet in height, but not in any sense a permanent one, for after a certain length of time (possibly hundreds of years) the conditions are changed by the deposition year by year of the dead vegetable matter resulting from these plants. This stage in development is usually known as low moor (German *Flach moor*), of which a beautiful example from near the foothills of the Rocky Mountains in Alberta is shown in the lower photograph on page 2949. Nearly all peat bogs, both in North America and in Europe, are underlaid with peat formed from this type of vegetation. As the conditions change, mosses tend to creep in, and it is at this stage we begin to encounter one of the most characteristic plants of the peat bogs. Bog moss, or *Spaghnum*, is abundantly distributed in the temperate regions of the world, always occurring in boggy areas where there is an abundant supply of water. The smooth stem of this little moss is densely covered with leaves which put out a branch at every fourth leaf. The stems grow freely at the top, while below, they and the leaves and branches slowly die away, forming by their remains fresh layers of peat. The leaves are so constructed that they contain a system of delicate, hollow chambers capable of absorbing a very large amount of water, so much so, that a given weight of this moss will often absorb forty to sixty times its own weight of water. Further, the dense growth of individual plants favors the retention of capillaries which eagerly suck in and firmly hold water, thus favoring a retention of water-level very near the surface of the peat. As the older plants die off and are converted into peat, the tops of the stems lengthen rapidly; thus one generation is founded upon another. In this way the Sphagnum moor continues to grow in height, surface and periphery, so long as the rainfall and the dew suffice. Thus there come to be thick, soft layers of bog moss which raise themselves to a considerable height, often building upwards more at the center than at the margin of the basin, and giving rise to a stage in the development of a peat bog known as high moor (German *Hoch moor*). When once the high moor is established it constantly spreads itself and invades fresh areas. On the soft, loose peat formed by *Sphagnum*, flowering plants find a foothold. In North America the most characteristic of these at this stage is the heath-like plant *Andromeda*, which can be recognized in the photograph on page 2951. This stage is by no means permanent, and usually rapidly results in the appearance of other characteristic plants in due course.

As the peat formed of the remains of the bog moss becomes consolidated the Arctic bramble (*Rubus Chamæmorus*), and Cowberry (*Vaccinium Vitis-Idæa*), spread in and replace *Andromeda*. This stage is illustrated in the lower photograph on page 2951, taken from a bog fifty miles north of Edmonton in Alberta. This stage is quickly replaced by the growth of Labrador Tea (*Ledum latifolium*), a small shrub, about a foot in height, with leaves bright green above and bronze colored underneath, bearing fragrant white flowers during June and July. It is very characteristic of all the peat areas in North America and, as its popular name indicates, grows far to the north in Labrador and Greenland. By the growth of these plants the peat has been further consolidated, and it is not long before seedling trees make their appearance. These are always evergreen conifers, and in the Northwest the black spruce is the first, and sometimes the only, species to find a foothold on the vegetation of peat bogs.

The conditions by this time are greatly changed. Seedling trees and shrubs are beginning to throw a dense shade upon the initial growth of the bog moss, and, further, leaf fall in the autumn results in the deposition of a thick layer of dead material over it. The water-level in the peat falls as the conditions become unfavorable for the growth of *Sphagnum*, and the whole history of development from this stage on

is in the direction of favoring a growth of shrubs, such as those indicated, with an ever-increasing dominance of black spruce This stage may be known as Ledum or Labrador Tea moor, and is a most familiar sight over very large areas of northern North America Associated with this are many plants which linger on from the earlier stages, but become gradually suppressed as the growth of the Labrador Tea becomes denser. A bog at this stage is shown in the photograph on this page This is a small bog west of Edmonton in northern Alberta, whose structure does not favor a retention of water and whose growth is not sufficiently vigorous or rapid to add anything to the thickness of the peat When the peat bog reaches this stage of development in northwest America it becomes a comparatively stable structure, and fits exactly the prevalent climatic conditions, for, as long as the conditions remain constant, this vegetation does not tend to change Such a type of vegetation is well described as the climax, and is illustrated in the photograph on page 2955 from an old bog

BOG IN NORTHERN ALBERTA AT THE LABRADOR TEA (*LEDUM*) STAGE OF DEVELOPMENT
The spruce usually occurring at this stage has been destroyed by fire a few years previously

where burning has taken place a few years earlier and most of the spruce typical of this stage of development has been destroyed Birch, which is frequently sparingly represented, is not permanently destroyed but springs up again from the root system.

As the trees increase in size and number *Sphagnum* entirely disappears, together with many of the plants characteristic of the earlier stage, and the ground now becomes covered with other types of mosses, chiefly belonging to the genus *Hypnum*, east of Jasper, Alberta A number of factors are, however, always tending to destroy the climax vegetation, and during the climax of the peat bogs the areas may be frequently swept by fire; or, in the course of development of a new country, the spruce and birch trees may be burned for fuel or destroyed by man. Such accidents often give rise to a series of new successions of vegetation which in some cases may be very different to those described, each one indeed sometimes offering a very complex problem

It must be clearly understood that although the majority of the bogs may have begun their development at approximately the same date, the rate of progress in different basins may vary greatly So at the present time we are able to study many examples at different stages of development. While it proceeds along parallel lines in northwest Europe, some of the plants at successive stages may be quite unlike Instead of the Ledum moor of North America we have the Scotch Ling few inches thawing during the summer, and even in the central and northern parts of Alberta many of the peat bogs remain frozen throughout the summer to a depth of about a foot. The material is also waterlogged, causing a deficiency of oxygen which militates against the rapid growth of vegetation The fertility of ordinary soil is partly dependent upon the easy access of oxygen to the upper layers, for, in the absence of oxygen, roots do not exhibit their reaction to the influence of gravity,

THE CLIMAX OR END STAGE OF DEVELOPMENT OF A PEAT BOG IN NORTHERN ALBERTA
Black spruce dominates and the bog moss has entirely disappeared

(*Calluna*) moor, covering large areas in northern England and Scotland

The peat bog represents a very special habitat for plant growth, the conditions in many respects being extreme. In the first place, peat is a very poor conductor of heat and in northern climates, where the winter is long, it becomes cooled to such an extent that its summer temperature always remains below that of an ordinary soil. In the far north and in the Yukon Territory the lower layers of peat remain permanently frozen, only the upper

growth is stunted and absorption of water and other materials inhibited. Certain substances very necessary for growth, such as nitrogenous materials and mineral matter, are scarce — factors which again tend to limit the growth of most plants. This may explain the peculiar features of peat bog plants, and their appearance in small areas surrounded by very different types of vegetation. One, which we should scarcely expect to find in plants growing in a waterlogged soil, is that they belong to a type of vegetation which exhibits structural pecu-

liarities tending to conserve water. The architecture of the leaf is such that water vapor can only escape slowly and with difficulty. These characteristics are found both in peat bog plants and also in those inhabiting the desert. The conservation of water may be carried out in several ways: by reduction of leaf surface, by rolling of leaves, by the development of hairs or wax on the surface of the leaf, and by the sinking deeply in the tissues of the leaf of the stomata, or small pores, through which the water vapor passes from the interior of the plant to the atmosphere. All these contrivances are found in the plants inhabiting the peat bogs, and suggest that they are living in a situation which is physically wet but physiologically dry. The difficulty may be due to slowness of absorption of water by the root system on account of low temperature and toxic substances, and, partly, to the structure of the wood of the root and stem through which the water has to pass on its way to the leaf. The actual loss of water from these plants would, without these precautionary measures, sometimes be exceedingly high, as the surface of the bog may reach a high temperature during the short summer months, and the wood be quite unable to conduct sufficient water to replace that lost by the leaves to the atmosphere.

The root system of many plants growing on peat, including the Labrador Tea, Scotch Ling, *Andromeda*, and the spruce, have their roots normally inhabited by fungi, which grow through the interior tissues and invest the exterior with a delicate mantle of hyphæ of microscopic size. This is not entirely confined to plants growing on peat, although it is especially common in such. In the case of the first three and several other peat plants, the fungus penetrates the whole plant, the delicate fungal hyphæ passing through the cell walls, and, in some cases, digesting the cells or, in other places, being themselves digested by the tissues of the host. In the Scotch Ling, according to some investigators, infection by the fungus seems to be necessary for growth, and it is found that the fungus penetrates the coat of the seed before distribution, so that each is infected before germination. The embryo is unable to produce normal roots except when infected in this way. It has not yet been decided whether the growth of these fungi in the tissues of the host plant results in the increase of nitrogenous material, but their universal presence suggests that they are of benefit in nutritional processes.

The physical features as regards the soil found in these areas are very characteristic of regions lying within the Arctic Circle, and we find that the majority of the moorland and bog plants have a distinctly arctic and sub-arctic distribution. From the geographical point of view, the vegetation of the peat bog may be described as a community of arctic and sub-arctic plants occupying areas inhabited by a temperate or southern vegetation. They often represent a collection of northern plants left behind during the immigration of the primitive flora, and becoming surrounded by a temperate vegetation which immigrated subsequently. Their presence in such situations is rendered possible nowadays by the fact that they inhabit areas which reproduce the soil conditions of their natural home. These characteristics are so different to those found in ordinary soils that they prevent the ingress of other plants that are not capable of coping with these conditions. Thus the peat bog is an area possessing special conditions as regards plant growth; it forms a close community entirely preventing the ingress even of plants which may be growing on the surrounding soil areas.

MARS AND THE MINOR PLANETS

Has a Planet Been Destroyed by Explosion in the Space between Mars and Jupiter? Or Has a World Failed to Form?

THEORY AND KNOWLEDGE ABOUT MARS

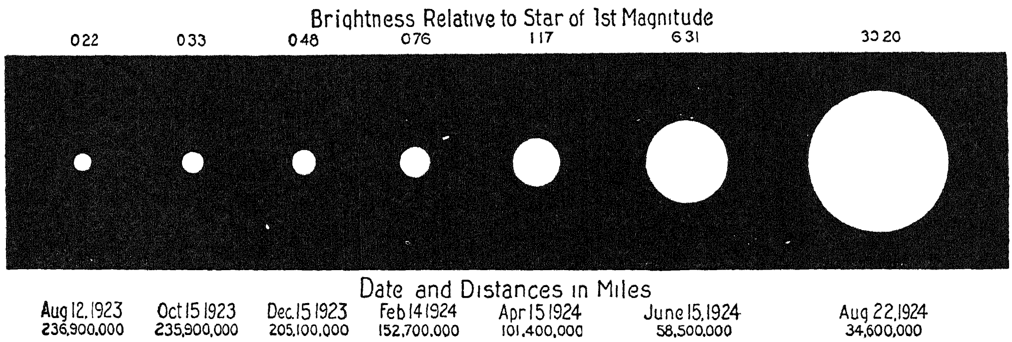
THE planet next outside the orbit of the earth is Mars. Because of its ruddy, fiery color it has received the name of the ancient god of war. It is a little planet, very much smaller than our own. Its diameter is only a little over 4200 miles; its surface area a little more than a quarter of the earth's surface; its volume is only about one-seventh, and its mass is less than one-ninth, of the volume and mass of our planet. The density of its materials is considerably less than the average density of terrestrial materials, and gravity on the surface of Mars is only 38 per cent of what it is with us, so that a mass weighing a hundred pounds on earth would weigh only thirty-eight pounds on Mars.

The amount of light and heat received from the sun is, surface for surface, less than one-half of that received by the earth; and this obviously implies a very cold climate on Mars, unless, as some suggest, the thinness of the Martian atmosphere, allowing the sun's rays to pass through very freely, permits a warmer temperature than we should expect from the planet's distance from the sun. The mean distance of Mars from the sun is 141,390,000 miles, as compared with earth's distance from the sun of 93,000,000; and the distance from the sun to Mars at perihelion, or its nearest point, is 128,200,000 miles; and at aphelion, or its furthest point, is 154,580,000 miles. At its nearest point Mars is therefore twenty-six million miles nearer to the sun than at its furthest point, so that its orbit is notably eccentric, and is indeed more eccentric than the orbit of any other of the smaller planets, excepting Mercury.

The distance between Mars and the earth varies within very wide limits. When Mars is on the other side of the sun from the earth — that is to say, when it is in conjunction — its distance from us averages 234,400,000 miles; but when it is on the other side of the earth from the sun — that is to say, is in opposition — its distance from the earth is anything from 35,000,000 miles to 61,000,000 miles, according to the point in the eccentric Martian orbit in which the opposition occurs. Mars is in opposition at intervals of twenty-six months, and at these times is to the south and high in the heavens at midnight. Its disc is at the same time far larger than at any other point in its orbit, so that the times of opposition give peculiarly favorable opportunities for examining its surface. Indeed, the apparent diameter of Mars varies from about three and a half seconds at conjunction to a little more than twenty-five seconds at opposition. When nearest to the earth, Mars has three times the brilliancy of Sirius, the brightest star in the heavens, and when farthest from the earth its brightness is reduced to that of a star of the second magnitude.

Mars completes its orbit round the sun in 687 days, or one year and ten and a half months, and travels along it at the rate of fifteen miles a second. The orbit is slightly inclined to the ecliptic, by rather less than two degrees. The planet rotates on its own axis. The clear markings on its surface have made it possible to determine the speed of that rotation with great accuracy, so that it is known that the Martian day is slightly over thirty-seven minutes longer than ours.

Like the earth, Mars is somewhat compressed at the poles, which are clearly visible under favorable circumstances by the white polar caps. Mars further resembles the earth in respect that it does not spin vertically to the plane of its orbit, but its equator is inclined by about $23\frac{1}{2}°$ to that plane, being much the same degree of inclination as the earth's. Mars must have changes of season, though each season is nearly twice as long as ours. The white polar caps (possibly snow and ice) grow and decrease in size with the change of seasons. Markings and color also change.

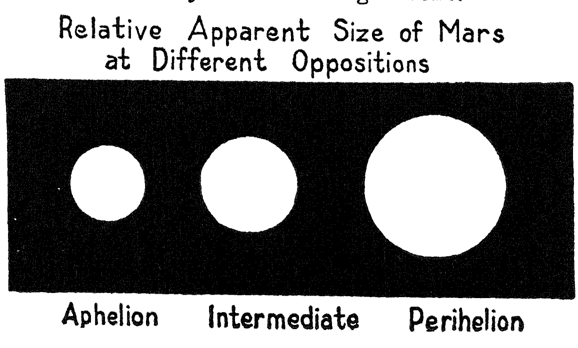


CHANGES IN THE APPARENT SIZE OF MARS

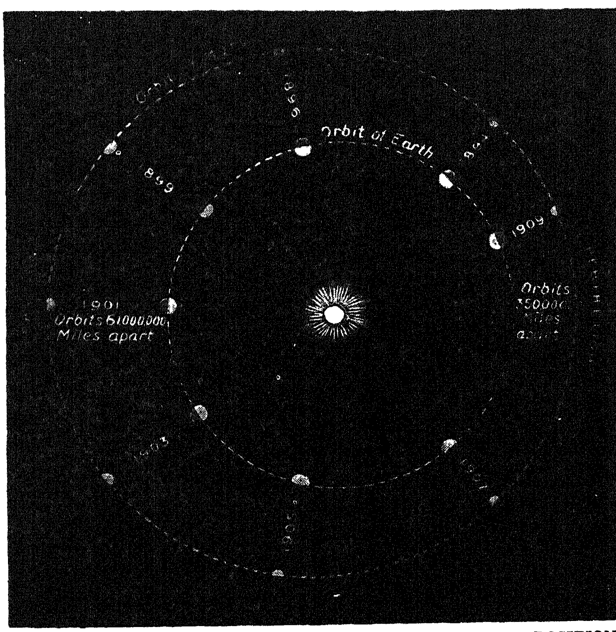
In August, 1923, Mars was in conjunction and at its greatest distance from the earth; it was in quadrature in April, 1924, and showed the gibbous phase (not shown in this diagram). In August, 1924, it was in opposition and closest to the earth

Area for area, the disc of Mars is a better reflector than that of the moon, twice as good as that of Mercury, but far inferior to Venus. Being outside the orbit of the earth, this planet never assumes the crescent phase, but the full circle of the disc is at times slightly impaired, giving Mars the gibbous shape of our moon when about three days from full moon. This occurs when the planet is in quadrature — that is to say, when the lines from earth to sun and from earth to Mars are at right angles. To the unaided eye, Mars, like every other planet, appears as a mere point of light and not as a disc at all. If its approximate place be known, it may be distinguished by its red color, but it must be remembered that several fixed stars are also ruddy.

Owing to the earth's revolution in its orbit round the sun, the apparent path which Mars, or any other planet, traces in the heavens is complicated, when the planet is in opposition, or in inferior conjunction, by a remarkable loop which it appears to describe within its normal orbit and in the contrary direction. That is to say, although Mars for the most part moves daily eastward among the stars, it appears, when on the opposite side of the earth from the sun, to turn and move westward for a time, and then to resume its eastward journey. This loop in the apparent orbit of the planets presented serious difficulties to the astronomers of old, who regarded the earth as stationary and all other celestial bodies as wheeling about our globe, and they were forced to devise a system of complicated movements to account for these apparent retrogressions.



Mars possesses an atmosphere which, though much less dense than ours, resembles it in many respects. Its presence is seen in the fact that the planet's disc is brighter towards the edge than in the center; for, as the brilliancy of Venus shows, atmosphere is the most effective of reflectors; and the rays of sunlight entering the edge of the disc of Mars encounter a deeper reflecting layer of atmosphere than those rays which fall upon its center. Again, the markings on the planet's surface are sharply defined only towards the center of the disc, but lose their clearness, and finally disappear altogether, as they are brought by the diurnal rotation towards the edge. The polar icecaps, which increase in size through every Martian winter, and diminish through the summer, are further evidence of an atmosphere in which moisture is carried, and from which it is precipitated in the form of snow; and certain white spots and other markings which appear occasionally, and are inconstant in form and position, are believed to be clouds floating in the atmosphere of Mars.



ORBITS OF MARS AND THE EARTH, SHOWING THEIR POSITIONS RELATIVE TO ONE ANOTHER AND TO THE SUN

Since the earth goes round the sun in 365 days, and Mars in 687 days, and the earth travels the faster, it follows that after the earth has passed Mars on any given date, a little over two years must elapse before the earth catches up to Mars again. This sometimes occurs at places where the orbits are close together, as in the opposition of 1909, when Mars was only 36,200,000 miles away from us.

The spectroscope has shown that this atmosphere is fairly similar to our own, and also that it contains a very small amount of aqueous vapor. The light from Mars gives the spectrum of sunlight, crossed by the dark lines similar to those it would exhibit if it had passed through the terrestrial atmosphere. Of course, the light from Mars, before it reaches the spectroscope, has actually traversed the atmosphere of the earth; and this fact, if it were not provided against, would vitiate the conclusion that these dark absorption lines are due to a Martian atmosphere resembling our own. In order to avoid any such fallacy, astronomers have made simultaneous spectroscopic observations of the light from Mars and of that from our moon, which is practically denuded of atmosphere. Both of these lights have passed equally through the terrestrial air; and the conclusions with regard to the Martian atmosphere are based on the difference between the two spectra. The light from Mars shows absorption lines which are absent from the light of the moon.

Mars has two very small moons, which revolve very close to the planet itself. They are so minute that, though often sought for, they escaped observation until 1877, when Asaph Hall of the U. S. Naval Observatory, Washington, made them out after long and sedulous watching with the best telescope which existed at the time. These two moons had long been expected, but on insufficient grounds. It was then thought, incorrectly, that whereas the earth had one moon, Jupiter had four, and Saturn eight; and it was felt to be suitable that Mars should have two, in which case each of these three planets outside our own would have double the number of satellites possessed by the planet within its orbit.

The two satellites were named by Professor Hall, after two characters in Greek

mythology, Deimos and Phobos, meaning Terror and Fear, who were attendants on the God of War. Deimos, the outer satellite, is distant about 14,600 miles from the center of Mars; its period of revolution, thirty hours and eighteen minutes, differs so slightly from the planet's period of rotation, that it must pass very slowly across the Martian sky. Indeed, about five and a half days must elapse from the time when it rises to the next time it rises. The orbits of both of the satellites are circular, and lie in the plane of the planet's equator. Deimos is estimated to be about five or six miles in diameter, and to throw on Mars a light equal to about one twelve-hundredth part of the light which our moon throws on the earth.

A little moon that rushes madly round Mars three times a day

Phobos, the inner satellite, is at a distance of only 5800 miles from the center of Mars — that is to say, a distance not greatly exceeding the diameter of the planet itself. It is a little larger than its companion moon, having a diameter of about seven miles, or a little more; and because of its nearness to the planet it is a much better luminary than the other, throwing a light equal to about one-sixtieth of the light of our moon. Its period of revolution — seven hours and thirty-nine minutes — is the shortest known period in the whole solar system. It makes over three circuits of Mars in the Martian day, and consequently rises in the west, and sets in the east. These two moons — one crossing the sky from east to west so slowly as to take over two and a half days from its rising to its setting, the other crossing the sky rapidly and frequently in the contrary direction, and both going through all their phases of new, crescent and full moon in these brief periods of thirty and seven and a half hours respectively — would seem strange if we could only see them.

Divergent views as to the nature and origin of the markings on Mars

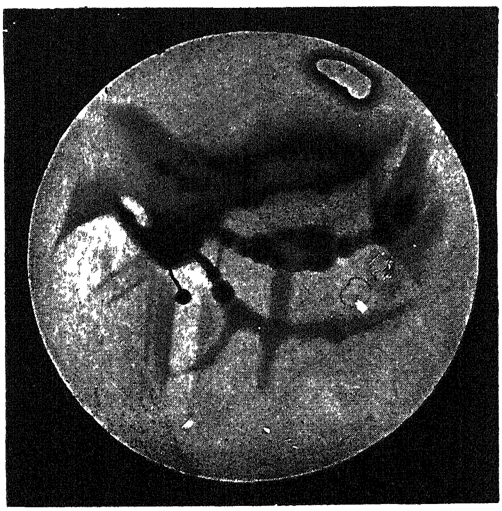
For over two centuries, ever since Herschel with his improved telescope made out the more prominent markings on the surface of Mars, the nature and origin of these markings have been the subject of great interest and also of much controversy. In the beginning it was thought that the darker areas were seas and the lighter areas land; later observations, however, showed definitely that there were no bodies of water on Mars, and that the dark areas moreover were traversed by certain extended and fairly narrow bands or stripes which could not have retained their permanence on the surface of an ocean or sea. The discoverer of these markings was Giovanni Schiaparelli (1835–1910); he supposed them to be channels for water, and he accordingly gave them the Italian name for channels — which is *canale*.

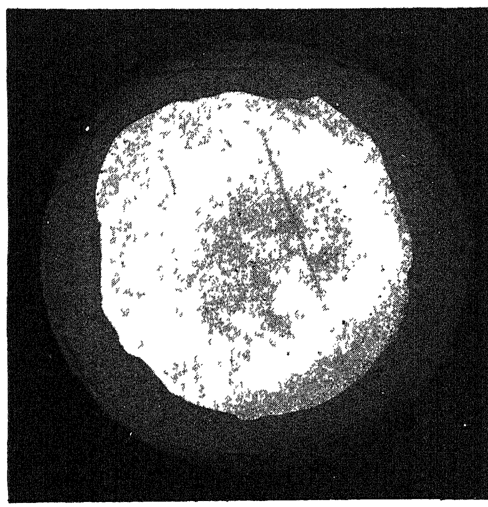
How the theory of "canals" and the Martian superman arose

This word was translated into English as "canal", which suggests artificiality. In fact, to some observers, especially Lowell, the markings seemed to have such wonderful regularity and signs of intelligent purpose that he took them to be unmistakable evidence of the existence on Mars of a race of highly intelligent beings who have developed an extraordinary degree of engineering ability, all the resources of which are devoted to the establishing and maintaining of a vast system of irrigation for the purpose of making the greatest possible use of the diminishing supply of water on the planet, a supply which is essential to the very continuance of the life of the race. This view has been shared by a number of other astronomers, but is for the most part looked on as lacking solid foundation in observational facts. It is indeed an interpretation which is doubtful in many ways, though not intrinsically impossible. It is hardly likely that the question can be settled in our day, unless astronomy receives the aid of much more powerful telescopes than are as yet at our disposal, or of other sources and means of investigation than those we now possess. Mars is one hundred and fifty times as far away as our moon; and perhaps the best telescopic view which we get of it is not much better than that which we get of the moon with unaided vision.

And in fact there is a very marked divergence of opinion, among astronomers who have devoted a great portion of their lives to observations of Mars, as to the shape and appearance of these so-called canals. The most noted representatives of these diverging views are Percival Lowell, who from 1894 until his death in 1916 devoted the major part of his energies to the study of Mars, and Professor W. H. Pickering who observed Mars from 1890 to the time of his death in 1938. According to Lowell's drawings and estimates the canals are long, perfectly straight, clearly defined lines, ranging from a couple of hundred miles in length to several thousand miles, the longest one extending over a distance of 3500 miles; while in width they vary from 2 or 3 miles up to some 15 or 20 miles for most of the large ones, some few exceptional canals being 100 or 200 miles wide. According to Pickering, the markings are rather broad, ill-defined bands, a few of them, especially the narrowest, being straight, but most of them being curved; a few are very narrow lines but most of them range from 100 to 600 miles in width. Lowell also claimed that at times some of the canals underwent a very remarkable process of doubling, so that they appear as two perfectly parallel lines, each line being of uniform width throughout. Pickering denies that the gemination, as this doubling is called, is real and considers it as an optical illusion. As against the engineering theory of their origin, Pickering and others think that there is no indication whatever of artificial origin. It seems clear, therefore, that as yet no final decision can be made in the case, and it may be best to suspend judgment.

In our review of the solar system from the sun outward we have come to one large planet after another — Mercury, Venus, Earth, Mars; and presently, after crossing a vast space, we shall come to other much greater planets — Jupiter, Saturn, Uranus, Neptune, and of course out beyond Neptune little Pluto. Between Mars and Jupiter there is no large world, although the presence of some such planet might have been expected. There is here an apparent interruption of the uniformity of the system. Instead of the orbit of a single large planet, we find in this region a belt which is traversed by the orbits of a vast number of small planetary bodies, which are commonly known as the minor planets, asteroids or planetoids. A very probable explanation, based on the meteoric or planetesimal theory, is that in the region within this belt, and again in the region outside of it, the formation of planets by the falling together of meteorites has proceeded to its normal conclusion,





A SNOWSTORM ON MARS AND THE EXTRAORDINARY SPREADING OUT OF SNOW FROM THE SOUTH POLE

The first of these drawings shows what is probably the beginning of an extensive fall of snow on Mars; the second shows the snow-cap of the South Pole of Mars at its greatest extent. The snow covers, it will be seen, about a quarter of the planet.

so that definite large worlds, with or without satellites, have come into being; but over the area of this belt, which lies between Mars and Jupiter, the normal formation of a planet has been prevented, possibly by the disturbing influence of the vast mass of Jupiter.

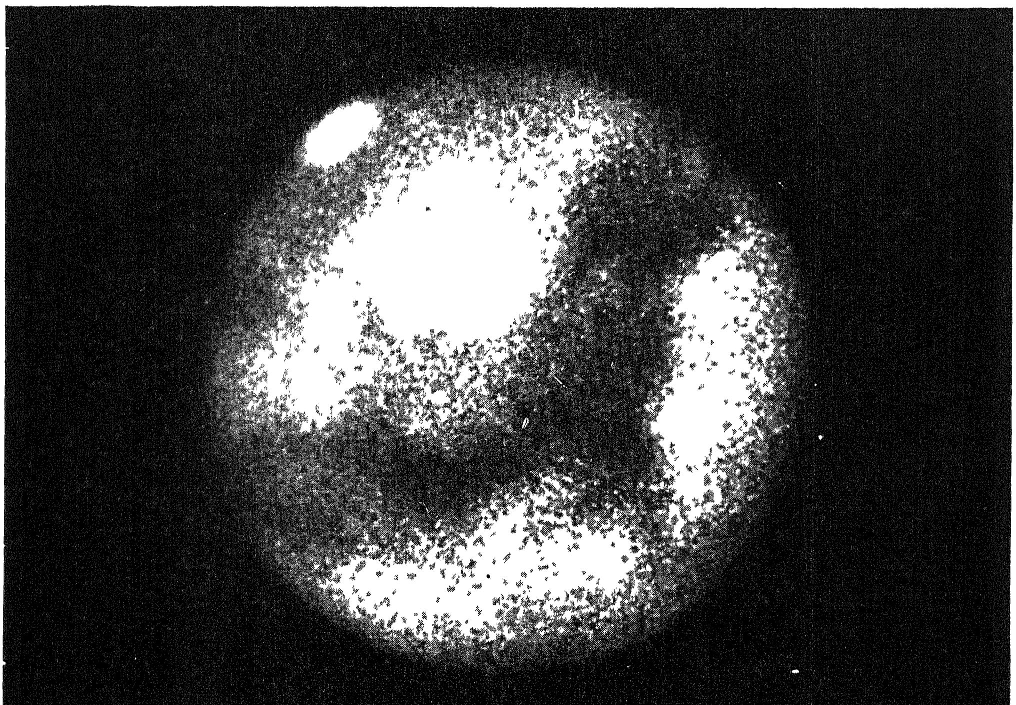
That curiously regular increase in the distances of the planets from the sun, which was first noticed by Titius about the middle of the eighteenth century, and, after its publication by J. E. Bode became known as Bode's Law, required the existence of a planet in this belt, which instead is scattered over with asteroids. It is now fairly certain that there is nothing at all in Bode's Law, except a coincidence. The "law" needs a good deal of straining to suit the distances of some of the planets, and Neptune disregards it altogether. Bode's formula is as follows: Set down the numeral 4 repeatedly. Leaving the first 4 as it stands, add 3 to the second, add 3×2 to the third, 3×4 to the fourth, 3×8 to the fifth, and so on, doubling the multiplier every time. Divide the resulting numbers by 10, and we are supposed then to have the mean distances of the series of planets from the sun, if the mean distance of the earth from the sun be taken as unity. The fifth term in this series requires a planet at a distance from the sun of the earth's distance multiplied by 2.8, and for this missing planet astronomers sought eagerly. For Bode's Law had not yet been discredited, and, quite apart from that theory, it was obvious that there was a tremendously large gap between Mars and Jupiter, which had not been accounted for.

MARS IN THE OPPOSITION OF SEPTEMBER, 1909

This drawing, by M Antoniadi of the Meudon Observatory, shows the appearance of the planet at 11 40 on the night of September 20, 1909, two days after it was nearest to the earth The Antarctic snow-cap is clearly shown at the top, and a number of canals are visible in the lower half

Towards the close of the eighteenth century an association of astronomers was formed for the purpose of hunting for the planet which was believed to be there. It was known that the object of their quest must be very small in size, or it would not so long have eluded observation. The first capture of an asteroid fell to Piazzi, a Sicilian astronomer, on the first day of the nineteenth century. He had long been engaged in a very exact method of mapping the sky, by which he determined the relative positions of all the stars within any particular area on several successive occasions. By this means he was able to detect if any star should move relatively to its neighbors and thus declare itself to be a planet. More than a hundred and fifty areas of the sky had thus been examined without success, when a comparison of four successive observations of the constellation Taurus showed Piazzi that a certain small star within it had changed its position in the constellation from one observation to another. This stranger was at first supposed to be a comet; but Bode, on hearing of its movements, claimed it for the planet which was required by his law of planetary distances from the sun. It was found to pursue an orbit in the vacant space between Mars and Jupiter. and was admitted, under the name of Ceres, as a member of our system. Piazzi observed the planet until February, when illness interrupted his labors; by the time his announcements reached the learned world the little planet was lost in the glare of the sun, and fear was felt that it would be impossible to locate it again. This stimu-

lated Gauss, who was then only twenty-five years old, to develop his method of calculating planetary orbits, and with the aid of his calculations Ceres was found once more on the last day of the year. In the following year a second asteroid was discovered, and named Pallas; this was followed by the discovery of Juno and Vesta; these are the four most conspicuous ones and were naturally discovered first. The orbits of about 1500 asteroids have been calculated up to the present time.



Courtesy Chicago University Press

A PHOTOGRAPH, GREATLY ENLARGED, OF MARS TAKEN BY BARNARD AT THE YERKES OBSERVATORY

Ceres, the largest of the minor planets, has a diameter of about five hundred miles. Of all their number, Vesta, which is the brightest, is the only one visible to even the keenest unaided vision. Many of them are very small indeed, and can only be seen through the most powerful telescopes; and in all probability there are many thousands, perhaps thirty thousand, more which are too small to be seen at all. The search for asteroids, which was long dependent upon direct telescopic observation, is now, like so many other scientific undertakings, a matter of photography. A camera is attached to a telescope moving by clockwork in such a way as to continue pointing to the same fixed stars. These stars therefore come out in the photograph as white points. But, when a long enough exposure is made, a planetary body, if there be any such within the field of the telescope, shows itself otherwise. It comes out, not as a point, but as a short white line, because of the movement it has made in its orbit during the exposure of the plate. This method, devised in 1891 by the German astronomer Max F. J. C. Wolf, has resulted in the discovery of many of the smaller asteroids.

It was by this method of photographic observation that the minute planetary body known as Eros was discovered in 1898 by Witt, of Berlin. Its discovery aroused great interest because it differed from the previously known asteroids, which circulate between Mars and Jupiter, by the fact that, though part of its orbit lies outside that of Mars, it is for the most

part between the orbit of Mars and that of the earth. Eros has an exceedingly eccentric orbit, and approaches to within fourteen million miles of the earth's path, so that with the exception of the moon it is by far the nearest body to the earth. But its very small diameter, which is less than twenty-five miles, kept it secret until sensitive plates were exposed night after night to the sky. On account of its closeness to the earth at times of opposition it offers a ready means of determining the solar parallax and hence the unit of astronomical distance.

The asteroids cover a very wide belt. Eros is only 12,000,000 miles further from the sun than the earth is; Priamus, discovered in 1917, is more than five times as far away from the sun as we are; its mean distance is 488,000,000 miles and at aphelion it recedes to a distance of 547,000,000 miles or some 40,000,000 miles further than Jupiter. Recently the asteroids Adonis, Apollo, and Hermes were discovered, each about 1 mile in diameter. The orbits of the asteroids differ considerably in shape and position from the orbits of the larger planets; they are often extremely eccentric, and are in many cases very steeply inclined to the plane of the ecliptic. Orbits are available for over 1500 asteroids, and probably 1000 more have been discovered, but they have not been observed sufficiently to have their orbits calculated.

Have the asteroids been formed by the explosion of a planet?

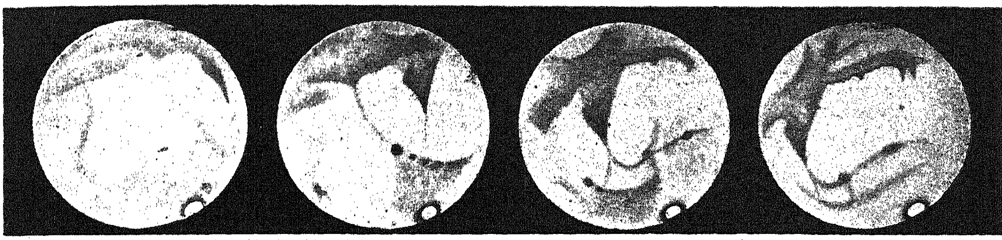
The mass of these tiny planets is very small. It is estimated that together they do not exceed a quarter of the mass of our earth. It is not yet clearly known why this space in the solar system, which should normally be occupied by a single planet with its satellites, is tenanted instead by an incoherent crowd of asteroids. It was at first believed that the minor planets were the scattered fragments of a planet which had in some way exploded and its pieces scattered. That view, however, has been given up, because it is known that the orbits of all these fragments, however greatly they might otherwise diverge, would have to pass through one point common to all of them — namely, the point at which the supposed explosion took place — but the widely various orbits of the asteroids do not, in fact, pass through or even near any common point, but form an inextricable tangle. This theory that the asteroids originated by explosion may, however, be amended so as to avoid the objection we have just mentioned. Some believe that the fragments formed by the first explosion subsequently exploded again, and yet again: and in that case a numerous swarm of asteroids, such as we see, might very well arise, having no common point in their orbits. But the theory, even in this improved form, is met by the further objection, which is practically insuperable — why should a planet explode? and why should its fragments explode again?

Have the asteroids been drawn into their positions by the influence of Jupiter?

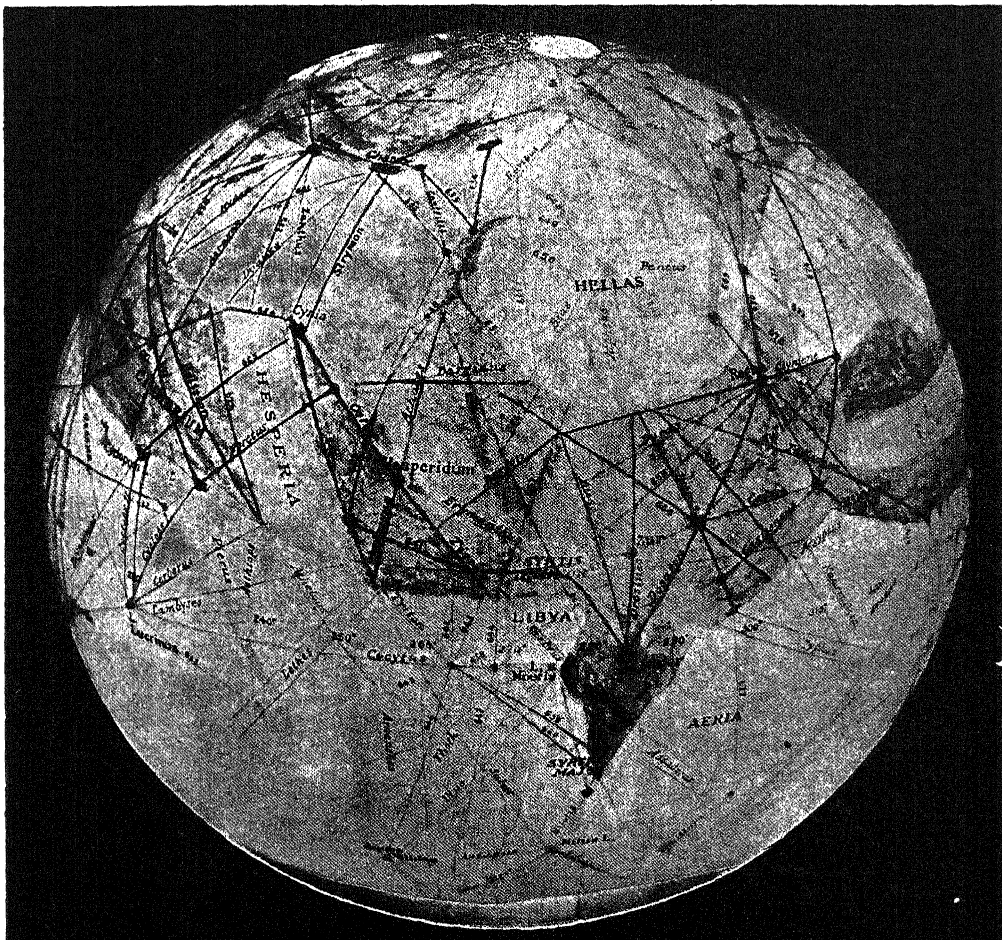
The other and more probable theory is that the matter destined to form each planet of our system was originally distributed in rings of meteorites round the sun, just as rings of meteorites circulate round Saturn; and that, although in the case of other planets the meteorites fell together into one body, those which circulated in the region between Mars and Jupiter were prevented from doing so by the enormous disturbances caused by the gravitation of Jupiter, the mass of which exceeds that of all the other planets put together, and may have had the effect of preventing the coalescence of the asteroids.

Indeed, there are certain facts which show in a very interesting way the power which Jupiter has exercised over the asteroids. If the distances of their various orbits be set down graphically on a chart, it is immediately apparent that at certain distances from the sun there are many of these orbits crowded closely together, but that at other distances there are blank spaces which contain no asteroids. It has been ascertained that these blank spaces are at exactly such distances from the sun that any asteroids having orbits in them would travel round the sun in such periods as to come frequently into the same rela-

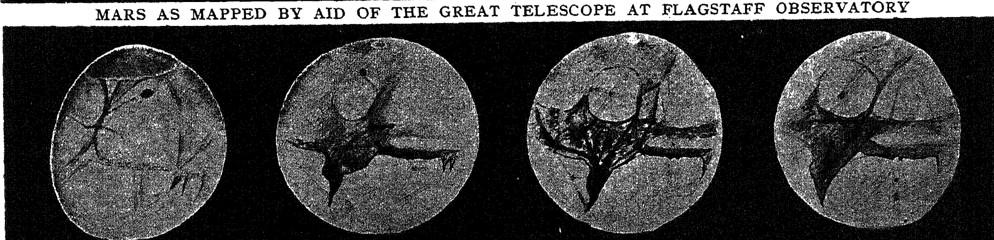
LOWELL'S DRAWINGS AND MAP OF MARS



CHANGES ON MARS IN ONE MONTH, SUPPOSED TO BE DUE TO CLOUDS, AND THEREFORE TO WATER



MARS AS MAPPED BY AID OF THE GREAT TELESCOPE AT FLAGSTAFF OBSERVATORY

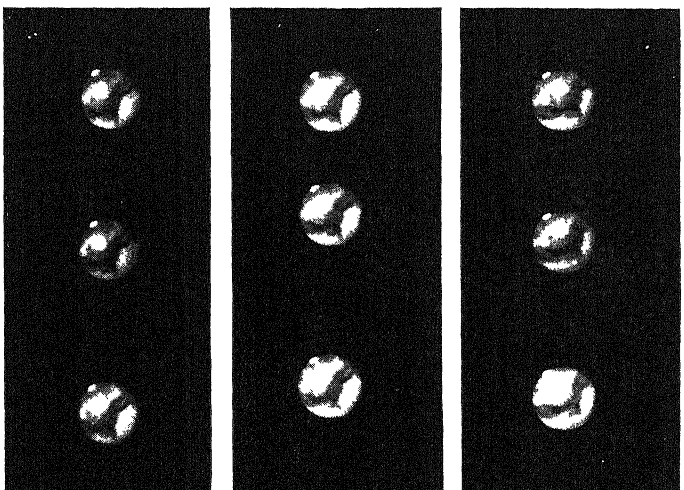


MELTING SNOW ON MARS, AND THE APPEARANCE OF DARK AREAS SUPPOSED TO BE VEGETATION

The changes observed in the bottom picture were spread over five months; according to Lowell these changes are due to the melting of snow and the running of the water down the canals, causing vegetation.

tions with Jupiter at the same points in their orbits. That is to say, no asteroid could retain an orbit in any one of these spaces, because Jupiter would so regularly and so often pull on it in the same way as to force it into an orbit at some other distance from the sun. Jupiter has swept these spaces clear of asteroids.

For example, at that distance from the sun at which an asteroid would revolve exactly twice round the sun for one revolution of Jupiter, any such asteroid would be pulled out of its orbit by the constantly recurring effect, in exactly the same place, of Jupiter's gravitation. This effect would reach a maximum at every revolution, until the asteroid had been forced to travel round the sun in a period which would not synchronize with Jupiter's period. The same process would affect any asteroid traveling, for example, five times round the sun for every two revolutions of Jupiter, so that a chart of the orbits of the minor planets contains blank spaces corresponding to a considerable variety of these numerical combinations. And, although Jupiter's attraction has thus acted in a prohibitive way upon minor planets which might otherwise have occupied orbits where there now are blanks, it must be remembered that the same attraction is always affecting the orbits of the asteroids, which are consequently always changing their paths to some extent, under the influence of this mighty planet.



Courtesy Chicago University Press

SUCCESSIVE PHOTOGRAPHS OF MARS, BY BARNARD, SHOWING CHANGES DUE TO ROTATION

The task of computing the orbits of the various asteroids, and of keeping track of them in the sky, has involved enormous labor, not only because they are so numerous, but even more because of the complexity which is introduced into their movements by the proximity of their powerful neighbor Jupiter. These calculations were until recently carried out by collaboration of many astronomers, especially in Germany, but it is now realized that it is possible to be too laborious, and that the ends of science will be sufficiently served if the chief asteroids are watched and the rest are abandoned.

Little is known of the asteroids themselves. Certain observers have reported an atmosphere about some of the largest of them; but the presence of any such mantle of air is extremely improbable, if not impossible, owing to the weakness of gravitative force in such minute bodies, and there appears to be no confirmation of its existence. The most significant fact yet ascertained is that several of them, notably Eros, vary greatly in brightness from time to time, and that these variations in reflective power are very swift and very erratic.

Now this irregular fluctuation in their brightness seems to show that the asteroids are not spherical but are shapeless lumps, detached mountains hurtling along through space, and presenting now a side, again an edge and again a corner to the earth. This jagged state of the asteroids would very well suit the theory which regards them as fragments of an ancient planet torn asunder by explosion. It does not however definitely exclude the other theory, which regards them as huge meteorites that have failed to coalesce into a planet.